60 GHz INTERSATELLITE LINKS
DEFINITION STUDY
FINAL REVIEW

FOR GODDARD SPACE FLIGHT CENTER
GREENBELT, MD

June 3, 1986

Ford Aerospace & Communications Corporation
Western Development Laboratories

(NASA-CR-[illegible]) NASA 60 GHz INTERSATELLITE LINKS DEFINITION STUDY. FINAL REVIEW (Ford Aerospace and Communications Corp.) 202 p CSCL 17B

N90-[illegible]

Unclas
G3/32 [illegible]

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AGENDA

- o SYSTEMS ENGINEERING
  - System and Technology Design Drivers
  - Operational Concept
  - System Design (All Baseband)
  - Acquisition Architecture Design
  - Channelized Crosslink
- o HARDWARE
  - Antennas
  - Receivers
  - Transmiters
  - Mechanical Design

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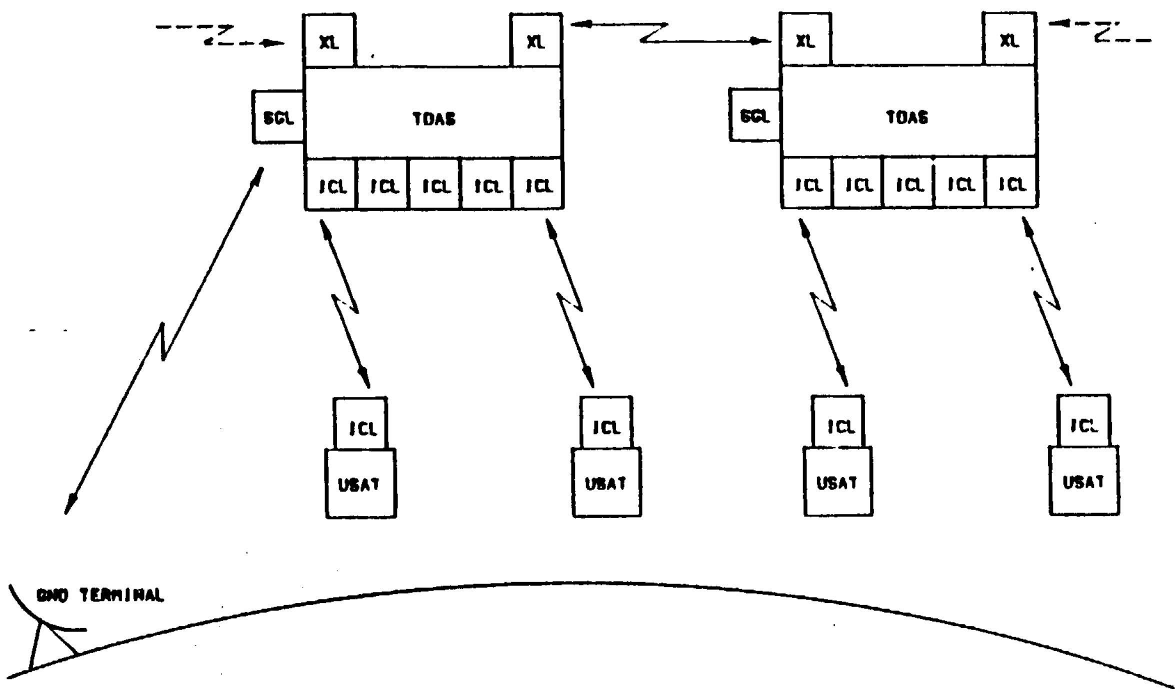
60 GHz REQUIRE NO NEW TECHNOLOGIES

- O ALL ENABLING TECHNOLGIES ARE IN WORK OR PLANNED
- O THE CROSSLINK SYSTEM CAN BE BUILT AT ANY TIME--DATA RATE IS THE ONLY ISSUE
- O RELIABILITY DOMINATES PERFORMANCE LEVELS

- RELIABILITY IS ONE OF THE MOST IMPORTANT PARAMETERS AT THIS TIME
- DATA RATE IS TIED DIRECTLY TO ATTAINABLE RELIABILITY LEVELS
- IMPROVED PARTS CHARACTERIZATION IS ESSENTIAL–PARTICULARLY FOR TRANSMITTERS
- TECHNIQUES FOR HARDWARE INTEGRATION AND CROSS-STRAPPING MUST BE IMPROVED TO ACHIEVE RELIABILITY GOALS WITHIN PHYSICAL CONSTRAINTS

SYSTEM CONCEPT



LEGEND:

TDAS - Tracking & Data Acquisition System (Satellite)
USAT - User Satellite
XL - Crosslink Package
ICL - Intersatellite Communication Link Package
SGL - Space/Ground Link Package

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ORIGINAL PAGE IS OF POOR QUALITY

GEOSYNCHRONOUS CROSSLINK SYSTEM REQUIREMENTS

ALL BASEBAND SYSTEM

- o Data rate - 2 Gb/s (bi-directional)
- o Bit error rate - 10^{-6}
- o Orbital configuration - GEO to GEO up to 160°
- o Eight-year life

INTERSATELLITE LINK SYSTEM REQUIREMENTS

- o Data Rate - 100 Kbps - 300 Mbps: LEO-GEO
  1 Mbps: GEO-LEO
- o BER - 10^{-6}
- o Orbital Configuration - 3-5 LEO Satellites
  Simultaneous Communication
  Orbital Altitudes 110Km-5000Km
- o Eight-year life

DESIGN PHILOSOPHY

- Minimum risk approach with TDAS constraints
- Minimize user (LEO) burden
- Maximize commonality to reduce cost
- Parallel solutions to protect flight hardware schedules
- Realistic hardware expectations to support early flight demonstrations

SYSTEM AND TECHNOLOGY DESIGN DRIVERS

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KEY SYSTEM DESIGN DRIVERS

- TDRSS legacy on TDAS influences 60 GHz system hardware requirement and emplacement.
- STS launch limits antenna's size and packaging.
- WARC-79 allocation forces innovative frequency planning.
- Potentially large LEO user ephemeris errors drive acquisition architecture.
- Potentially short GEO-LEO contact time dictates fast link acquisition design.
- Simultaneous (3-5) LEO operations impact system reliability, weight and size.
- Small percentage of sun-in-conjunction time leads to low noise front end approach.

KEY TECHNOLOGY DESIGN DRIVERS

- Gain, scanning and weight consideration lead to GDA (gimbal dish antenna) configuration
- Gimbal velocity and acceleration (not EIRP + G/T) dominates acquisition time
- Viterbi decoder complexity leads to novel coding approaches
- Low complexity (LC) FEC conserves GEO-LEO bandwidth.
- Low loss requirement favors beam waveguide approach
- Low noise front end dictates LNA over mixer front end

OPERATIONAL CONCEPT

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OPERATIONAL CONCEPTS

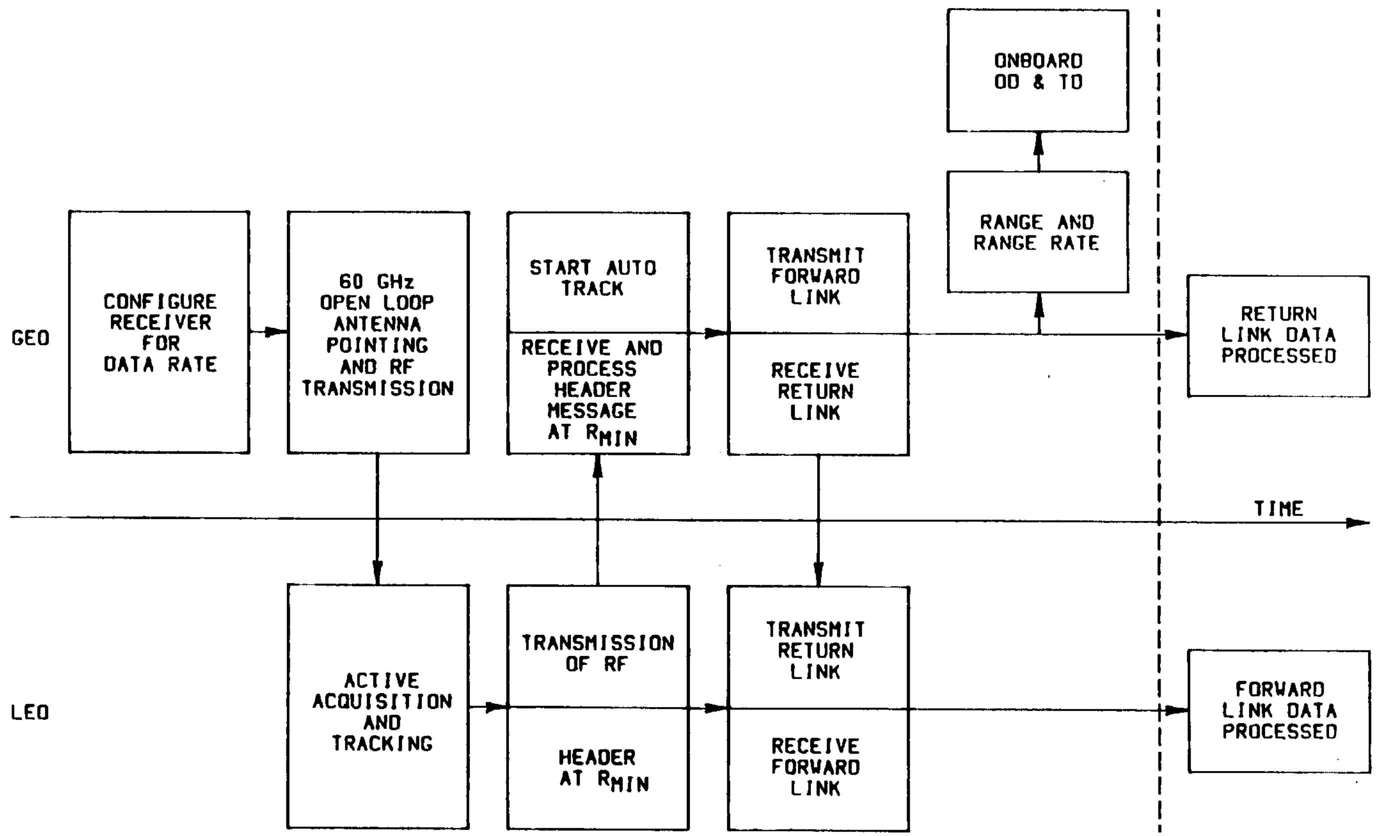
GEO-GEO

- Maintain 2 Gb/s link at all times (>99.99%) except, maintain 300 Mb/s link during sun-in-conjunction (<0.001%)

Scheduled GEO-LEO Contact

- GEO open loop radiates and waits for LEO user's acquisition and transmission
- Ground coordinates schedule to prevent
  - LEO in-conjunction-with each other
  - LEO-to-GEO return link in-conjunction-with sun at high data rate transmissions
- LEO user defines its own EIRP per its own data rate requirement and ICD (interface control document)

GEO-LEO CONTACT ACTIVITY SEQUENCE DIAGRAM



HEADER
- o RANGE PREAMBLE
- o DESTINATION AND ROUTING MESSAGES
- o USER OD AND TD UPDATES

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SYSTEM DESIGN

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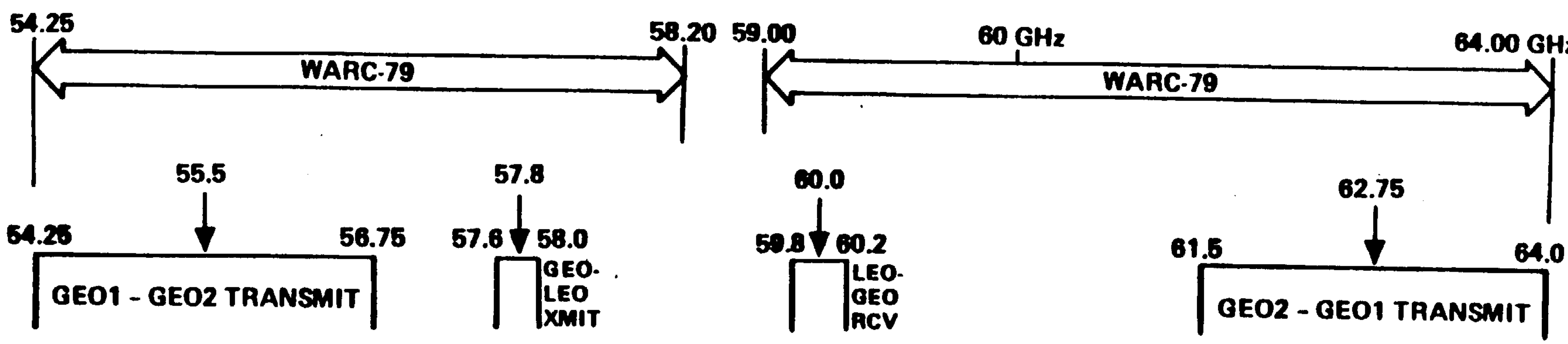
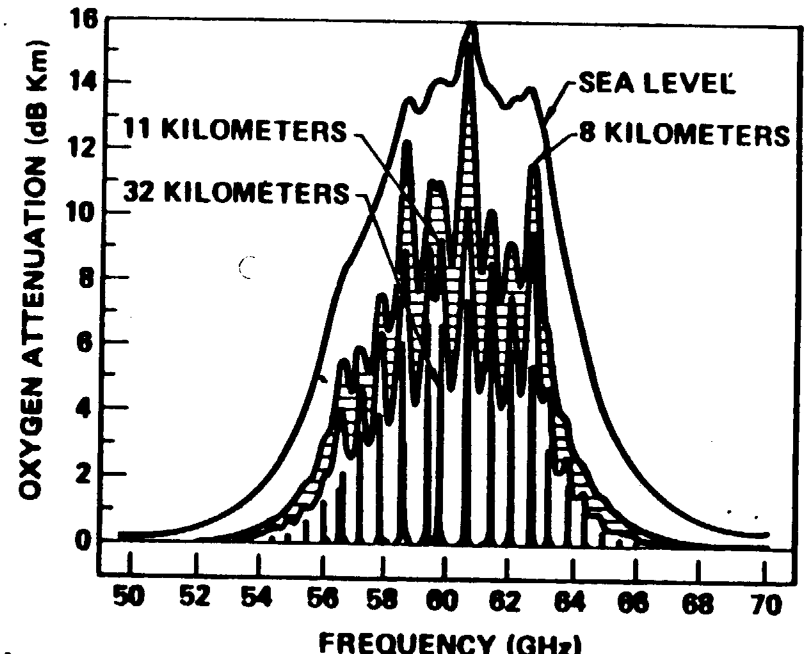
FREQUENCY PLANNING



- EARTH POINTING TRANSMISSIONS LOCATED IN BAND CENTER TO MINIMIZE TERRESTRIAL INTERFERENCE
- WIDE FREQUENCY SEPARATION FOR GEO-GEO TO MINIMIZE DIPLEXER LOSS



OXYGEN ATTENUATION FOR VARIOUS ELEVATIONS IN THE EARTH'S ATMOSPHERE

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INTERFERENCE ANALYSIS

SOURCE OF INTERFERENCE	REQUIRED* ISOLATION	IMPLEMENTATION	ISOLATION PROVIDED	MARGIN
o GEO #1 Transmit to Geo #1 Receiver	109 dB	o 7-Pole Chebyshev XMIT o 7-Pole Chebyshev RCVR	115 dB	6 dB
o Forward Link Xmitter to GEO Receiver	84 dB	o 3-Pole Chebyshev Forward Xmit o 7-Pole Chebyshev RCVR o 30 dB IF Quieting	88 dB	4 dB
o GEO-GEO Xmitter to LEO-GEO Receiver	98 dB	o 3-Pole Chebyshev RCVR o 40 dB IF Quieting	100 dB	2 dB
o Forward Link Xmitter to LEO-GEO Receiver	99 dB	o 3-Pole Chebyshev RCVR o 40dB IF Quieting	110 dB	11 dB
o Others	(Negligible)	---	---	---

*The intersymbol interference caused by the band-limiting will be

$\leq$ 1.03 dB for the LEO-GEO link.

$\leq$ 0.92 dB for the GEO-GEO link.

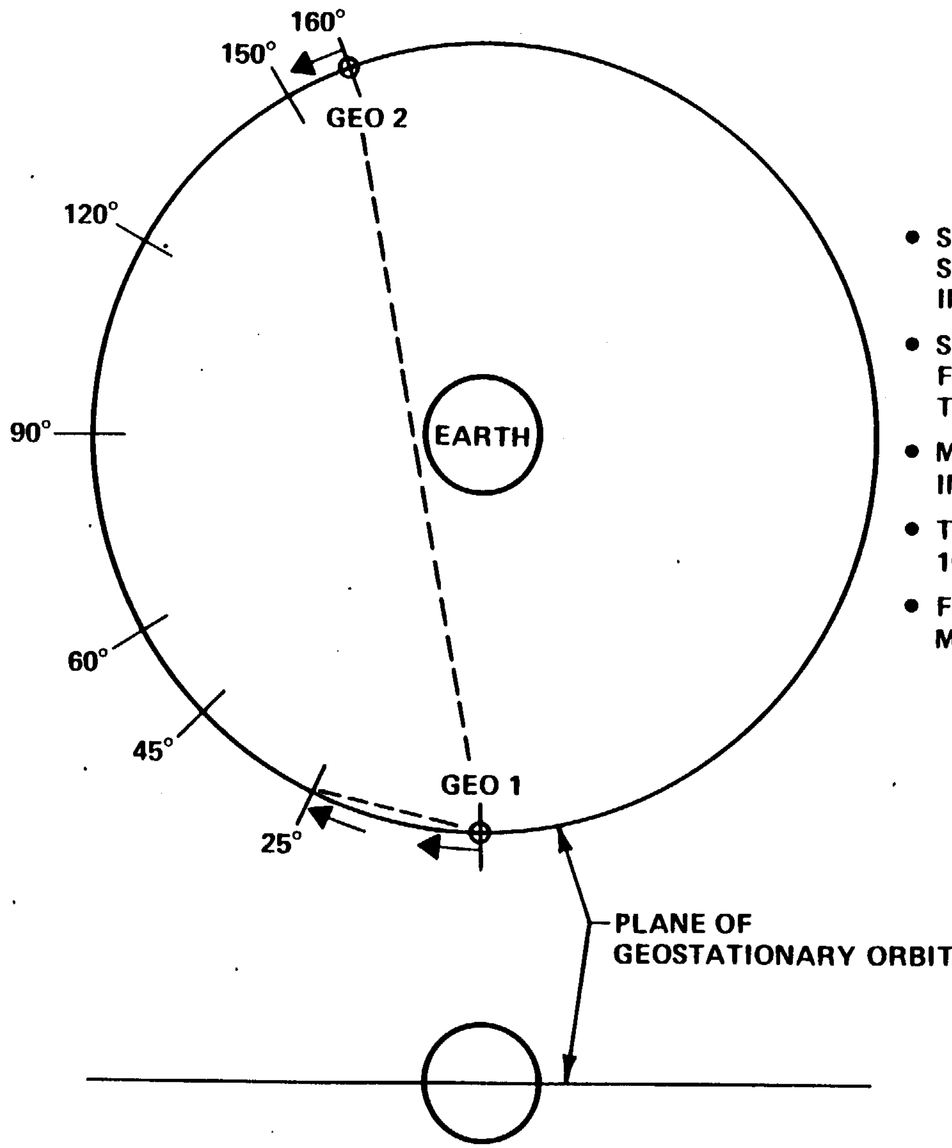
FREQUENCY AND TIMING CONSIDERATIONS

Item	Dominant Drivers	Derived Requirement or Performance
o Frequency stability	Range Rate accuracy	1×10^{-10}
o Ranging accuracy	DLL C/N	Can achieve $\pm$5 M accuracy
o Range Rate	Oscillator Noise	$\pm$2.0 mm/s

CODING/MODULATION

MODULATION	RATIONALE
GEO-GEO: QPSK (2 Gb/s)	- Non-linear power amp (10W) - Bandwidth efficient
LEO-GEO: QPSK	Same as Above
GEO-LEO: BPSK (1 Mb/s)	- Bandwidth insignificant
CODING	
GEO-GEO: No coding	Possible implementations in l992 time frame
LEO-GEO: Rate 5/6 LC FEC	- High coding gain - Bandwidth efficient - Parallels NASA technology development contract at Ford Aerospace
GEO-LEO: No coding	- Sufficient link margin - Minimum LEO user complexity

DURATION OF SOLAR INTERFERENCE
GEO to GEO Satellite Links



- SOLAR INTERFERENCE ONLY POSSIBLE WHEN SUN IS IN GEOSTATIONARY PLANE (AT EQUINOX IN MARCH AND SEPTEMBER)
- SUN IS WITHIN $\pm 1/2°$ OF GEOSTATIONARY PLANE FOR A MAXIMUM OF 2-3 CONTINUOUS DAYS, TWICE A YEAR
- MAXIMUM CONTINUOUS DURATION OF INTERFERENCE IS 4 MINUTES
- TOTAL MAXIMUM DURATION PER YEAR IS 16 MINUTES
- FOR A GIVEN LINK, INTERFERENCE OCCURS A MAXIMUM OF ONCE PER DAY

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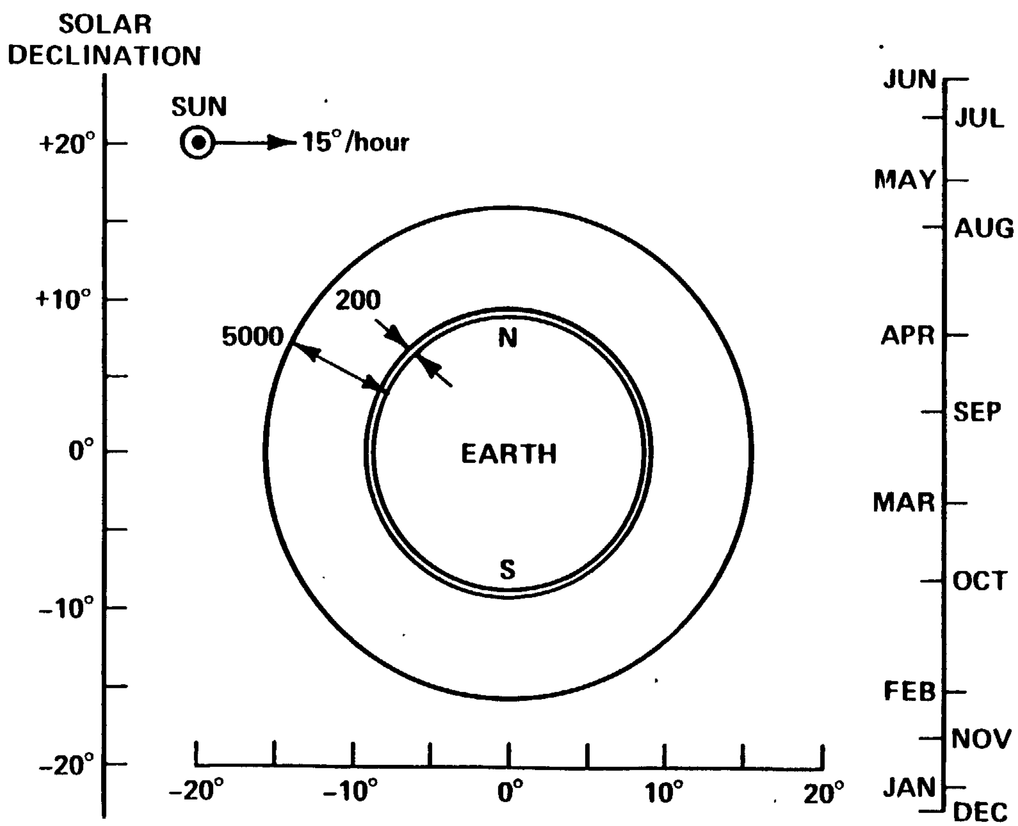
DURATION OF SOLAR INTERFERENCE
GEO Satellite Looking at LEO Satellite



GEO SATELLITE VIEW OF EARTH

- LEO ORBITS FROM 200 TO 5000 km
- SOLAR MOTION W TO E, UNIFORM 0.25 DEGREES PER MINUTE
  N S MOTION MAXIMUM OF 0.4 DEGREES PER DAY AT EQUINOX

SOLAR INTERFERENCE REGION DIAMETER 1° TO 2.3°, FOR ANTENNA SIZES 3.2 m TO 0.9 m

POSSIBLE INTERFERENCE WHEN SUN PASSES WITHIN AREA BOARDED BY ORBIT EXTREMES AND EARTH

MAXIMUM OCCURRENCE RATE, ONCE PER DAY

MAXIMUM DURATION DEPENDS ON LEO SATELLITE ALTITUDE AND ORBITAL INCLINATION

ALTITUDE (km)	DURATION (min)
200	5
500	8
1000	10
2000	12
5000	10

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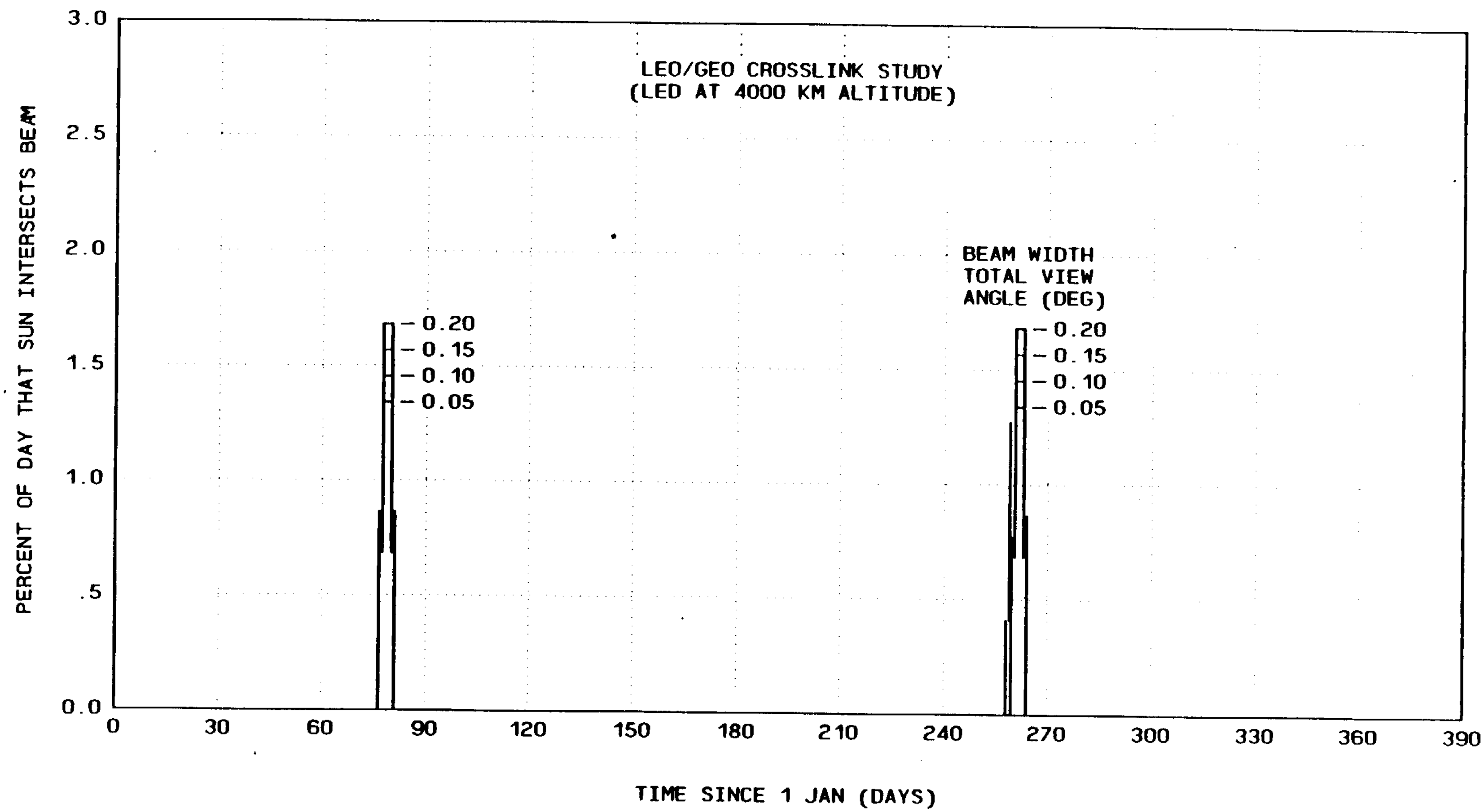
SPECIAL CASE: EQUATORIAL LEO ORBITS



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EFFECTS OF SUN

GEO-GEO LINK

- o Maintain 2 Gb/s for 99.99+ % of time
- o Maintain 300 Mb/s capability all the time
- o Link acquisition and tracking always maintained
- o Sun conjunction time predictable

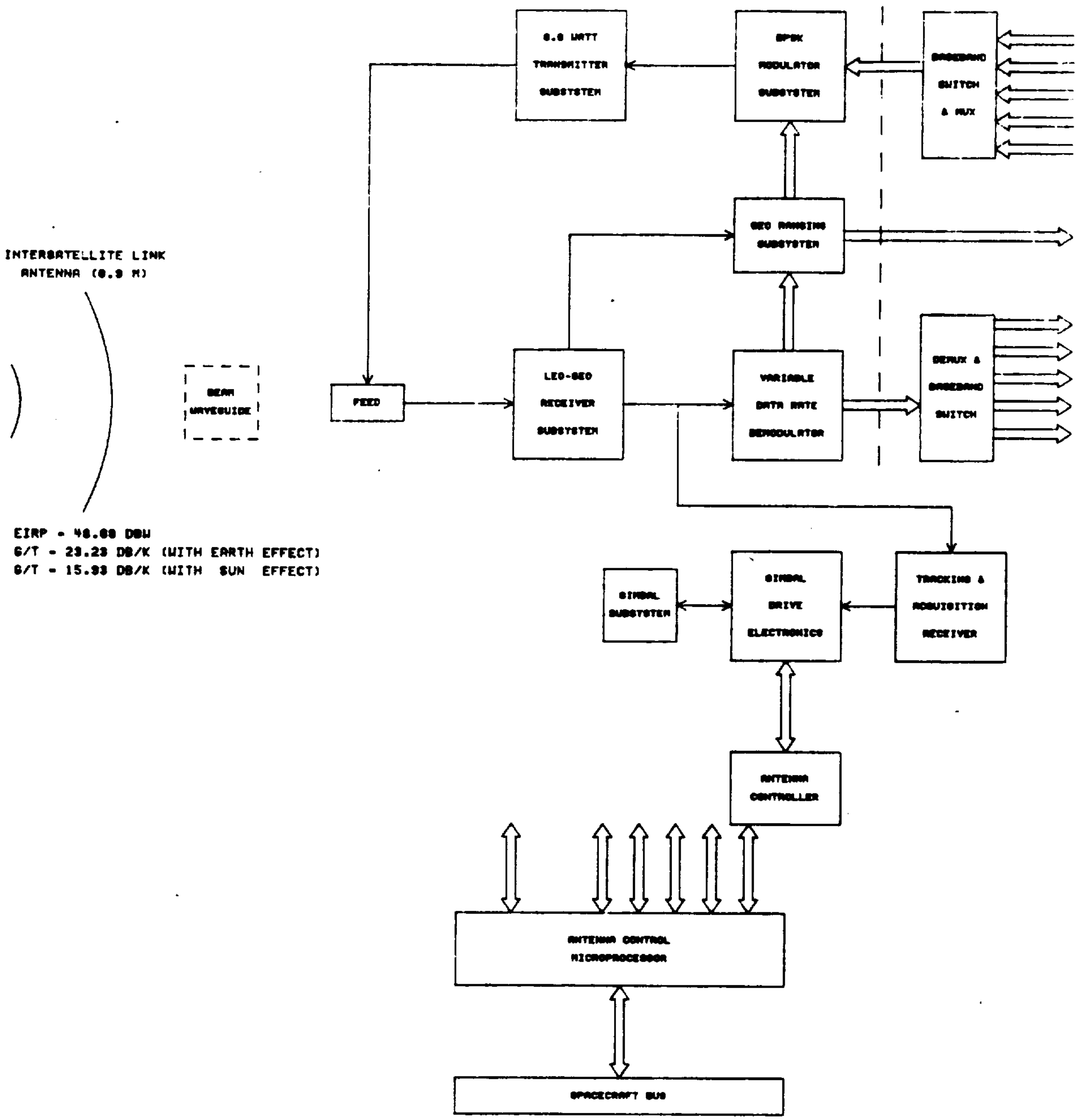
GEO-LEO LINK

- o Maintain Data Rate for 99.5% of time*
- o Link acquisition and tracking always maintained
- o Sun conjunction time predictable
- o Re-configuration for solar conjunction commandable from ground

*Solar conjunction capability at discretion of user LEO-GEO
Lower rates could be used during conjunction

EFFECT OF EARTH

- GEO-GEO link is independent of earth effect
- All GEO-LEO links maintain full capability at all times



GEO-LEO

INTERSATELLITE LINK COMMUNICATION SYSTEM

GEO EQUIPMENT

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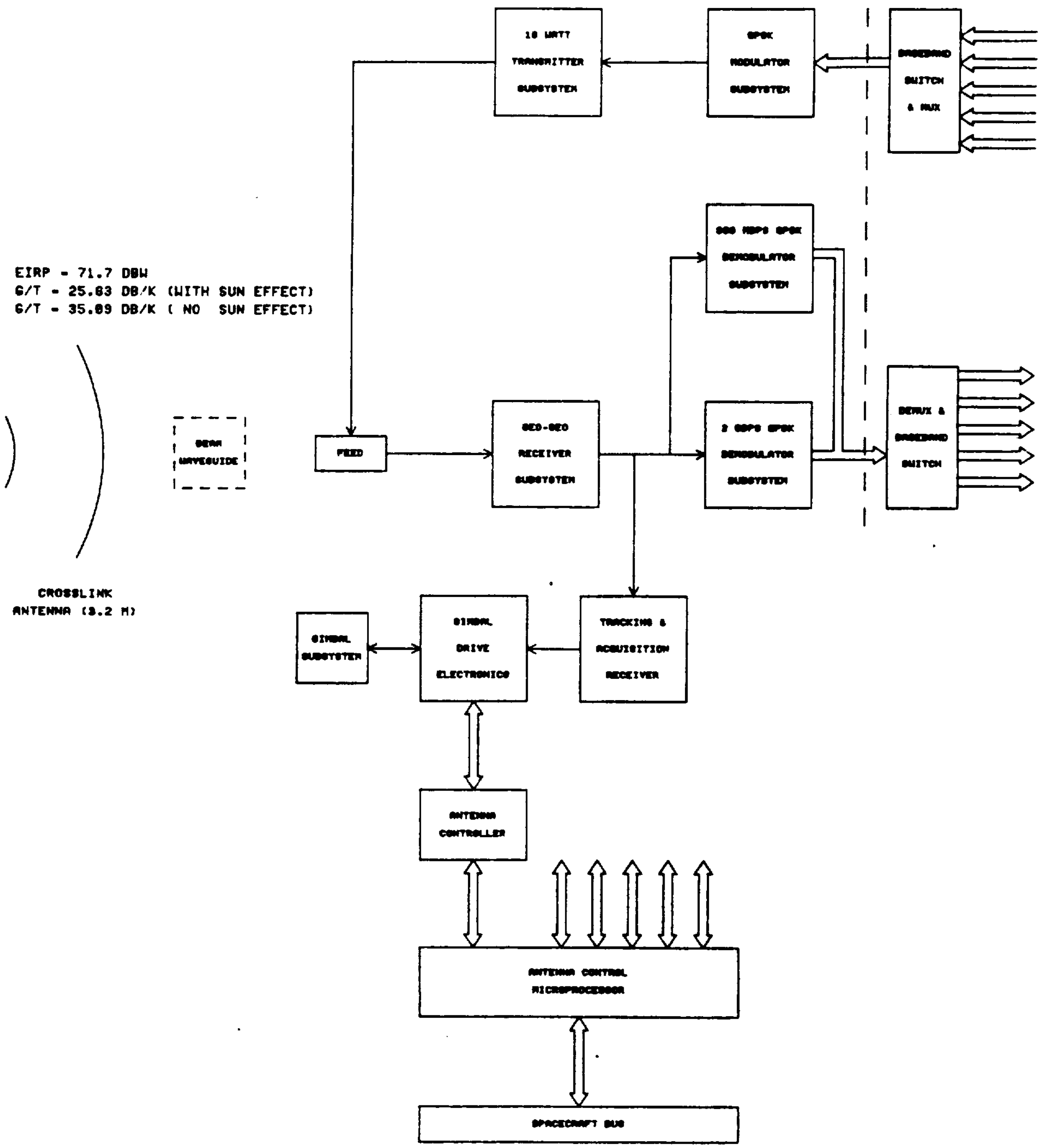

GEO-GEO

CROSSLINK COMMUNICATION SYSTEM

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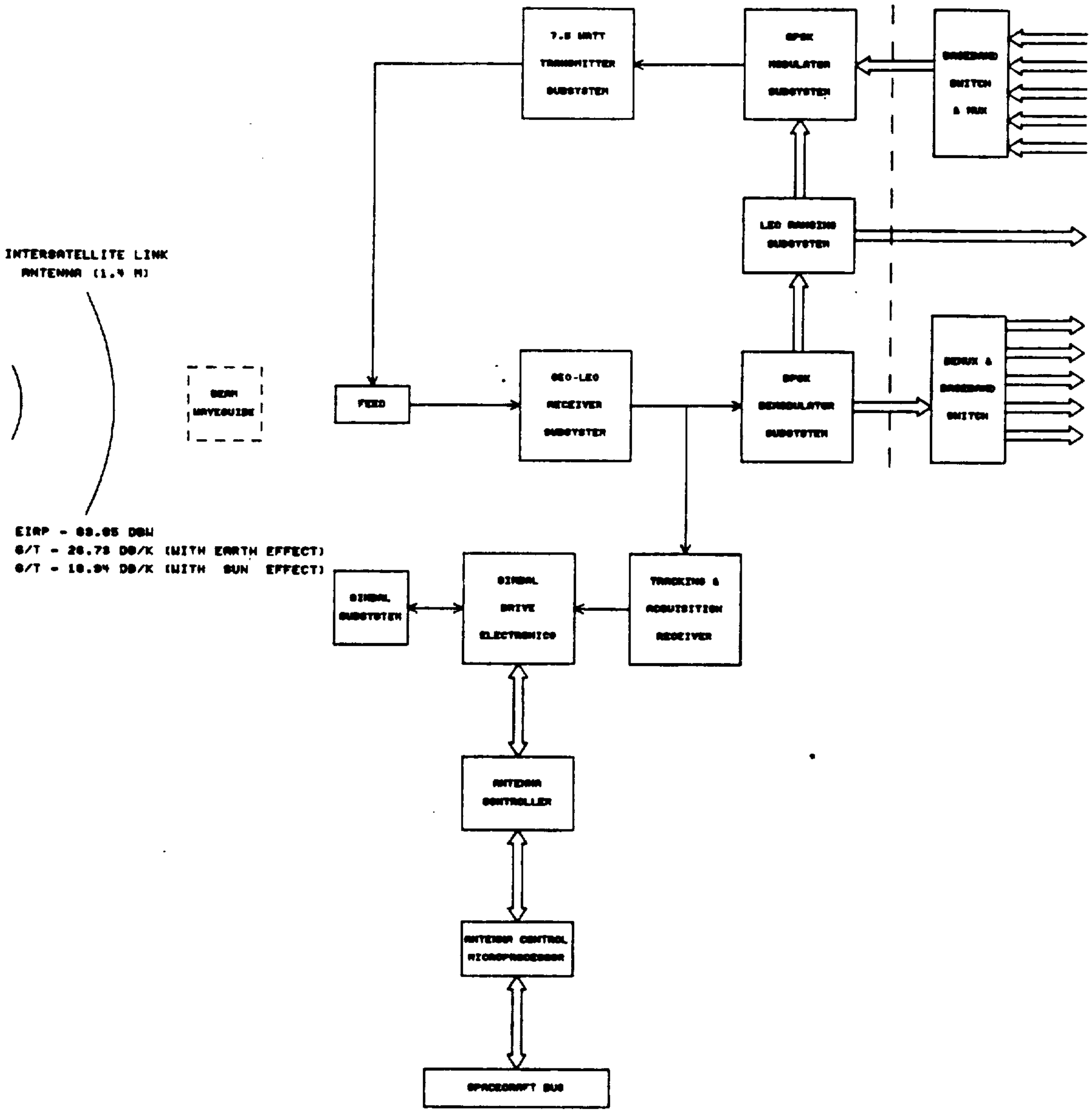

GEO-LEO

INTERSATELLITE LINK COMMUNICATION SYSTEM

LEO EQUIPMENT

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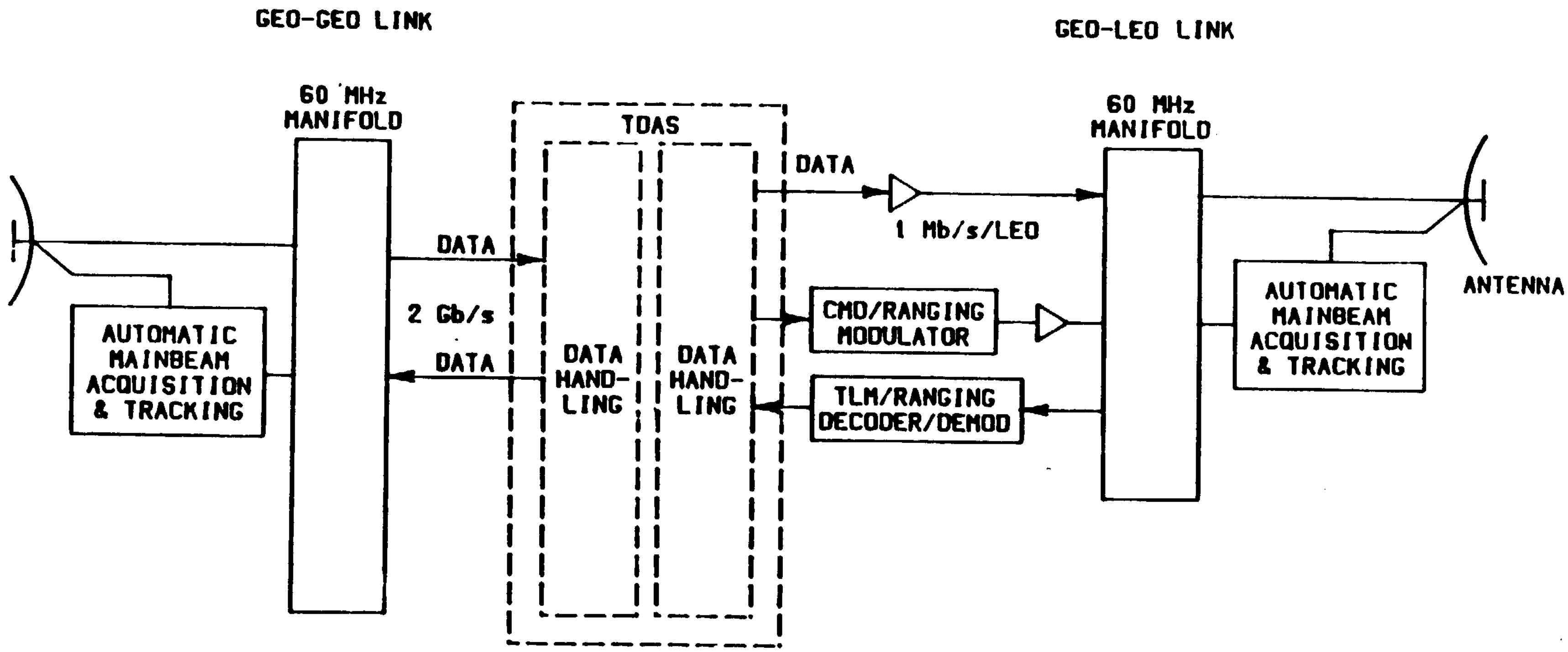
BASELINE ICLS/TDAS INTERFACE



1 GEO-GEO INTERFACE

- 10 WATTS
- 3.2M ANTENNA

3-5 GEO-LEO INTERFACES

- 0.6 WATTS
- 0.9M ANTENNA
- NO CODING

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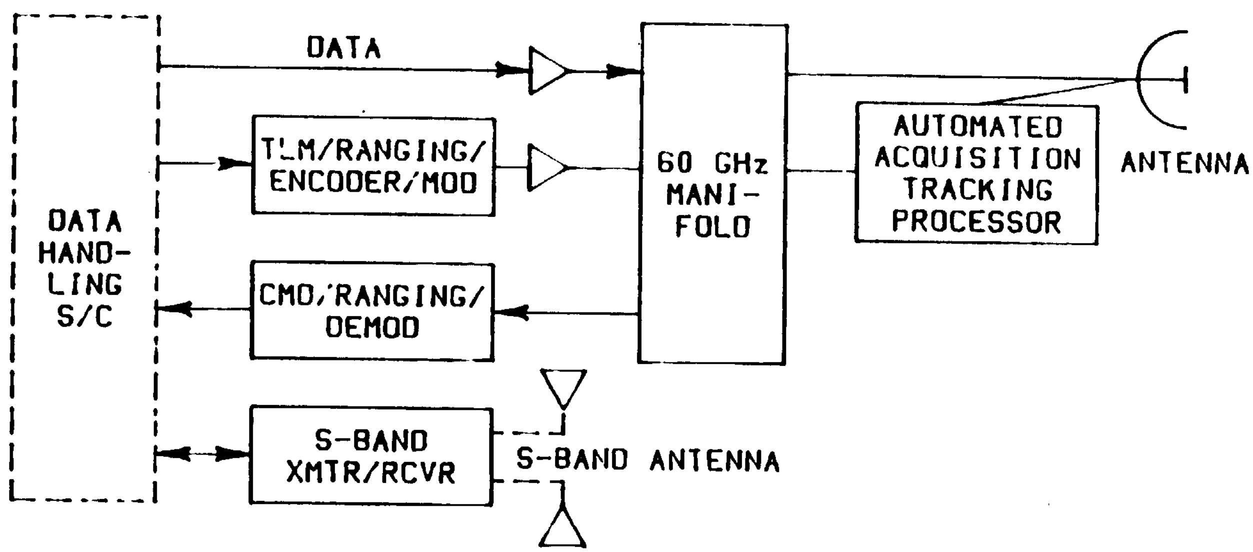
BASELINE ICLS/LEO USAT INTERFACE

LEO-GEO

INTERFACE

- 7.5W (300 Mb/s MAX)
- 4.6 FT ANTENNA
- 100 lb
- 200W DC POWER
- TLM DATA CDM 1 Mb/s
- DATA RATE USER SPECIFIED
- FEC ENCODING
- AUTOMATED MAINBEAM ACQISITION AND TRACKING



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SYSTEM COMMONALITY

	GEO TDAS	LEO-USER
COMMON	o 360^{o} K LNA (GEO-GEO, LEO-GEO)	o 360^{o} K LNA (GEO-LEO)
	o Acquisition Receiver	o Acquisition Receiver
	o 10 W Xmitter (GEO-GEO)	o 7.5 W Xmitter (LEO-GEO)
UNIQUE	o 0.6 W Xmitter (GEO-LEO)	
	o 3.2 M Antenna & Gimbal (GEO-GEO)	o 1.4 M Antenna & Gimbal
	o 0.9 M Antenna & Gimbal (GEO-LEO)	
	o 2 Gb/s and 100 Kb/s to 300 Mb/s Demod.	o 1 Mb/s Demod. & User TT&C Interface
	o 2 Gb/s and 1 Mb/s Modulator	o 100 Kb/s - 300 Mb/s Modulator*
	o FEC Decoder	o FEC Encoder
	<u>MORE COMPLEX</u>	<u>LESS COMPLEX</u>

*EACH LEO USER WOULD NOT HAVE FULL RANGE OF DATA RATES

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LINK ANALYSIS PARAMETERS AND CONVENTIONS

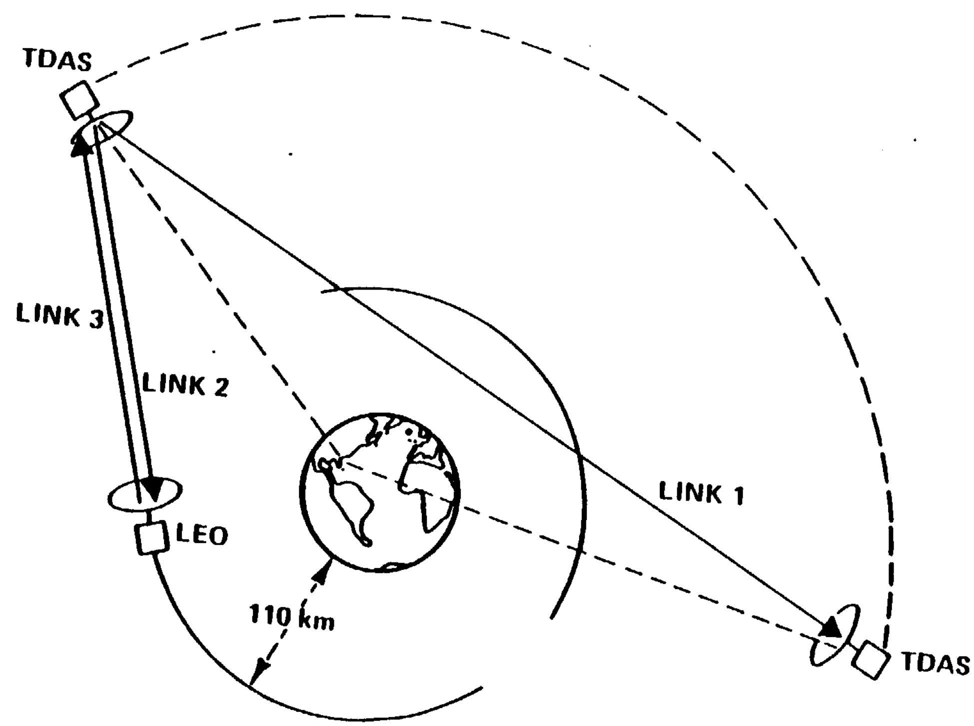
- o LINE LOSSES:
  PER LOSS BUDGET ATTACHED

- o CARRIER FREQUENCY:
  LINK 1: 62.75 GHz, 55.5 GHz
  LINK 2: 57.8 GHz
  LINK 3: 60 GHz

- o MAX LINK DISTANCE:
  LINK 1: 83043 km
  LINK 2,3: 41660 km

- o ACQUISITION TIME:
  (FOR GEO TDAS @ $\pm 0.2^o$)
  (FOR LEO USAT @ $\pm 2.0^o$)
  LINK 1: $\leq$27 sec (3.2 m ANT.)
  LINK 2: $\leq$44 sec (1.4 m ANT.)
  LINK 3: $\leq$ 3 sec (0.9 m ANT.)

- o ANTENNA TEMPERATURE:
  LINK 1S = 5200^oK
  LINK 2S = 5000^oK SUN
  LINK 3S = 4400^oK
  LINK 2E, 3E = 250^oK EARTH
  LINK 1E, = 10^oK



LINK SYSTEM SIZING

- EIRP
  - Antenna Diameter Limited by Launch Constraints (STS)
  - 1989 Technology Cut-off on Power
- G/T
  - 1989 Low Noise Front End
  - Acquisition Baseline Precludes Large Antennas

LINK ANALYSIS

- o Link losses
  - Feed (beam waveguide) loss (L1)
  - Network (incl. filters) loss (L2)

- o System noise temperature

  - Antenna noise temperature T_A (sun, earth, sky)
  - Feed noise temperature
  - Network noise temperature
  - Rcvr noise temperature

- o Polarization loss

- o Antenna pointing loss

- o Intersymbol interference loss

- o Modem implementation loss

FEED AND NETWORK LOSS ASSESSMENT (1989)

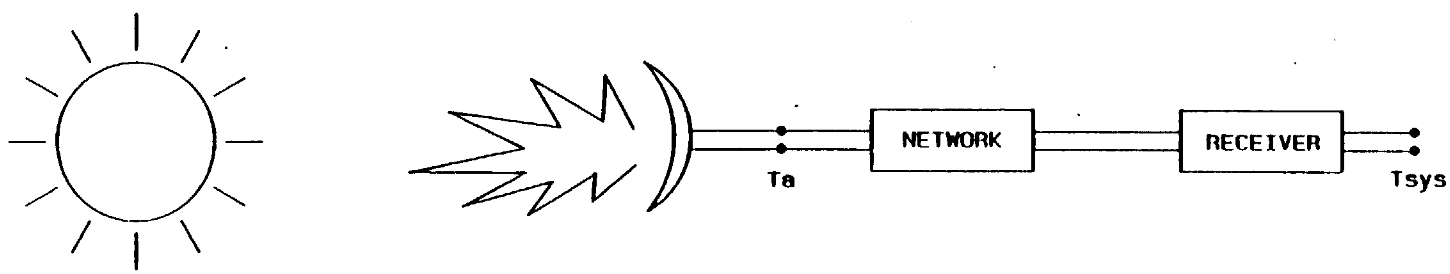
(IN DB)

	GEO/GEO		GEO/LEO (GEO)		GEO/LEO (LEO)	
ITEM	XMIT	RCVR	XMIT	RCVR	XMIT	RCVR
SWITCH	0.1	0.1	0.1	0.1	0.1	0.1
OUTPUT FILTER	0.3		0.5		0.5	
INPUT FILTER		0.3		0.5		0.5
COUPLER		0.2		0.2		0.2
SEPTUM POLARIZER	0.2	0.2	0.2	0.2	0.2	0.2
HORN COUPLER	0.1	0.1	0.1	0.1	0.1	0.1
WAVEGUIDE (0.25 M)	0.3	0.3	0.3	0.3	0.3	0.3
NETWORK TOTAL	1.0	1.2	1.2	1.4	1.2	1.4
BEAM WAVEGUIDE	0.6	0.6	0.6	0.6	0.6	0.6

ANTENNA NOISE TEMPERATURE ASSESSMENT

ANTENNA DIAMETER (m)	0.9	1.0	1.4	1.5	2.0	3.0
FULL POWER BEAMWIDTH (DEGREES)	0.84	0.76	0.54	0.50	0.38	0.25
DIAMETER BETWEEN 2ND NULLS (DEG)	1.73	1.56	1.11	1.04	0.78	0.52
ANTENNA TEMPERATURE (K)						
POINTED AT SUN @ 7200 K	4400	4500	5000	5000	5100	5200
POINTED AT EARTH @ 290 K	250	250	250	250	250	250
POINTED AT SKY @ 3 K	10	10	10	10	10	10

MAGNITUDE OF SOLAR INTERFERENCE



SUN AT 60 GHz

Taver = 7200K
= 0.53^{o}

ANTENNA

Size = .9 to 3.2 M
Beamwidth = $.3^{o}$ to 0.11^{o}
Efficiency = 0.62
Antenna Temperature (Sun)
Ta = 4400 to 5200K

NETWORK

Loss Total = 1.6-2.0 dB

RECEIVER

Tr = 360 K

SYSTEM TEMPERATURES

Point at Sun = Tsys 3200 to 3800K
Point at Earth = 600K
Point at Sky = 438K

BASELINE PARAMETERS

GEO-GEO

- 10 W xmit, 3.2 m antenna
- 2 Gb/s 99.9% time
- 300 Mb/s 0.01% (sun)

LEO-GEO

- 7.5 W xmit, 1.4 m (LEO), 0.9 m (GEO)
- 300 Mb/s @ > 99.5% time
- 50 Mb/s 0.5% (sun)

GEO-LEO

- 0.6 W xmit (GEO)
- 1 Mb/s 100% time

LINK PERFORMANCE SUMMARY

LINK	CAPABILITY	MARGIN
GEO-GEO	2 Gb/s Without Sun Effect (99.99% of Time)	2.8 dB
	300 Mb/s With Sun Effect (0.0%)	1.7 dB
GEO-LEO	1 Mb/S At All Times	11.1 dB With Earth Effect 3.3 dB With Sun Effect
LEO-GEO	300 Mb/s With Earth Effect FEC	2.1 dB
	50 Mb/s With Sun Effect FEC	2.8 dB

GEO-GEO Crosslink with Sun Effect

Modulation: QPSK
Coding: None

Carrier Frequency = 55.5 GHz

Parameter	Value	Units	Remarks
Transmitting S/C Power	10.00	dBW	10.0 watts
Transmit Line Loss	1.00	dB	
Feed Loss	0.60	dB	
Transmitting Antenna Gain	63.30	dBi	3.2-m dish
EIRP	71.70	dBW	
Free Space Loss	225.72	dB	83,043 km
Pointing Loss	0.10	dB	0.01 degree
Polarization Loss	0.20	dB	
Tracking Loss	0.10	dB	0.01 degree
Net Path Loss	226.12	dB	
Receiving S/C Antenna Gain	63.30	dBi	3.2-m dish; Temp. =5200 K
Feed Loss	0.60	dB	Temp.= 10 K
Receive Line Loss	1.20	dB	Temp.= 290 K
Receiver Temperature			360 K
System Noise Temperature	35.87	dB-K	3866.6 K at Receiver Input
Effective G/T	25.63	dB/K	
Received Carrier Level	-92.92	dBW	At Receiver Input
Boltzmann's Constant	-228.60	dBW/Hz-K	
Received C/No	99.80	dB-Hz	
ISI Degradation	0.77	dB	
Modem Loss	2.00	dB	
Data Rate	84.77	dB-Hz	300 Mb/s
Available Eb/No	12.26	dB	
Required Eb/No	10.50	dB	BER = 10^{-6}, uncoded
Coding Gain	0.00	dB	
Eb/No Margin	1.76	dB	

GEO-GEO Crosslink without Sun Effect

Modulation: QPSK
Coding: None

Carrier Frequency = 55.5 GHz

Parameter	Value	Units	Remarks
Transmitting S/C Power	10.00	dBW	10.0 watts
Transmit Line Loss	1.00	dB	
Feed Loss	0.60	dB	
Transmitting Antenna Gain	63.30	dBi	3.2-m dish
EIRP	71.70	dBW	
Free Space Loss	225.72	dB	83,043 km
Pointing Loss	0.10	dB	0.01 degree
Polarization Loss	0.20	dB	
Tracking Loss	0.10	dB	0.01 degree
Net Path Loss	226.12	dB	
Receiving S/C Antenna Gain	63.30	dBi	3.2-m dish; Temp. = 10 K
Feed Loss	0.60	dB	Temp.= 10 K
Receive Line Loss	1.20	dB	Temp.= 290 K
Receiver Temperature			360 K
System Noise Temperature	26.41	dB-K	437.6 K at Receiver Input
Effective G/T	35.09	dB/K	
Received Carrier Level	-92.92	dBW	At Receiver Input
Boltzmann's Constant	-228.60	dBW/Hz-K	
Received C/No	109.27	dB-Hz	
ISI Degradation	0.92	dB	
Modem Loss	2.00	dB	
Data Rate	93.01	dB-Hz	2000 Mb/s
Available Eb/No	13.34	dB	
Required Eb/No	10.50	dB	BER = 10^{-6}, uncoded
Coding Gain	0.00	dB	
Eb/No Margin	2.84	dB	

LEO-GEO Crosslink with Earth Effect

Modulation: QPSK
Coding: Rate 5/6 FEC

Carrier Frequency = 60.0 GHz

Parameter	Value	Units	Remarks
Transmitting S/C Power	8.75	dBW	7.5 watts
Transmit Line Loss	1.20	dB	
Feed Loss	0.60	dB	
Transmitting Antenna Gain	56.90	dBi	1.4-m dish
EIRP	63.85	dBW	
Free Space Loss	220.41	dB	41,660 km
Pointing Loss	0.07	dB	0.02 degree
Polarization Loss	0.20	dB	
Tracking Loss	0.03	dB	0.02 degree
Net Path Loss	220.71	dB	
Receiving S/C Antenna Gain	53.00	dBi	0.9-m dish; Temp. = 250 K
Feed Loss	0.60	dB	Temp.= 10 K
Receive Line Loss	1.40	dB	Temp.= 290 K
Receiver Temperature			360 K
System Noise Temperature	27.77	dB-K	598.6 K at Receiver Input
Effective G/T	23.23	dB/K	
Received Carrier Level	-105.86	dBW	At Receiver Input
Boltzmann's Constant	-228.60	dBW/Hz-K	
Received C/No	94.97	dB-Hz	
ISI Degradation	1.03	dB	
Modem Loss	2.00	dB	
Data Rate	84.77	dB-Hz	300 Mb/s
Available Eb/No	7.17	dB	
Required Eb/No	10.50	dB	BER = 10^{-6}, uncoded
Coding Gain	5.40	dB	
Eb/No Margin	2.07	dB	

LEO-GEO Crosslink with Sun Effect

Modulation: QPSK
Coding: Rate 5/6 FEC

Carrier Frequency = 60.0 GHz

Parameter	Value	Units	Remarks
Transmitting S/C Power	8.75	dBW	7.5 watts
Transmit Line Loss	1.20	dB	
Feed Loss	0.60	dB	
Transmitting Antenna Gain	56.90	dBi	1.4-m dish
EIRP	63.85	dBW	
Free Space Loss	220.41	dB	41,660 km
Pointing Loss	0.07	dB	0.02 degree
Polarization Loss	0.20	dB	
Tracking Loss	0.03	dB	0.02 degree
Net Path Loss	220.71	dB	
Receiving S/C Antenna Gain	53.00	dBi	0.9-m dish; Temp. =4400 K
Feed Loss	0.60	dB	Temp.= 10 K
Receive Line Loss	1.40	dB	Temp.= 290 K
Receiver Temperature			360 K
System Noise Temperature	35.07	dB-K	3217.1 K at Receiver Input
Effective G/T	15.93	dB/K	
Received Carrier Level	-105.86	dBW	At Receiver Input
Boltzmann's Constant	-228.60	dBW/Hz-K	
Received C/No	87.67	dB-Hz	
ISI Degradation	0.79	dB	
Modem Loss	2.00	dB	
Data Rate	76.99	dB-Hz	50 Mb/s
Available Eb/No	7.89	dB	
Required Eb/No	10.50	dB	BER = 10^{-6}, uncoded
Coding Gain	5.40	dB	
Eb/No Margin	2.79	dB	

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GEO-LEO Crosslink with Earth Effect

Modulation: BPSK
Coding: None

Carrier Frequency = 57.8 GHz

Parameter	Value	Units	Remarks
Transmitting S/C Power	-2.22	dBW	0.6 watts
Transmit Line Loss	1.20	dB	
Feed Loss	0.60	dB	
Transmitting Antenna Gain	52.70	dBi	0.9-m dish
EIRP	48.68	dBW	
Free Space Loss	220.08	dB	41,660 km
Pointing Loss	0.03	dB	0.02 degree
Polarization Loss	0.20	dB	
Tracking Loss	0.07	dB	0.02 degree
Net Path Loss	220.38	dB	
Receiving S/C Antenna Gain	56.50	dBi	1.4-m dish; Temp. = 250 K
Feed Loss	0.60	dB	Temp.= 10 K
Receive Line Loss	1.40	dB	Temp.= 290 K
Receiver Temperature			360 K
System Noise Temperature	27.77	dB-K	598.6 K at Receiver Input
Effective G/T	26.73	dB/K	
Received Carrier Level	-117.20	dBW	At Receiver Input
Boltzmann's Constant	-228.60	dBW/Hz-K	
Received C/No	83.63	dB-Hz	
ISI Degradation	0.00	dB	
Modem Loss	2.00	dB	
Data Rate	60.00	dB-Hz	1 Mb/s
Available Eb/No	21.63	dB	
Required Eb/No	10.50	dB	BER = 10^{-6}, uncoded
Coding Gain	0.00	dB	
Eb/No Margin	11.13	dB	

GEO-LEO Crosslink with Sun Effect

Modulation: BPSK
Coding: None

Carrier Frequency = 57.8 GHz

Parameter	Value	Units	Remarks
Transmitting S/C Power	-2.22	dBW	0.6 watts
Transmit Line Loss	1.20	dB	
Feed Loss	0.60	dB	
Transmitting Antenna Gain	52.70	dBi	0.9-m dish
EIRP	48.68	dBW	
Free Space Loss	220.08	dB	41,660 km
Pointing Loss	0.03	dB	0.02 degree
Polarization Loss	0.20	dB	
Tracking Loss	0.07	dB	0.02 degree
Net Path Loss	220.38	dB	
Receiving S/C Antenna Gain	56.50	dBi	1.4-m dish; Temp. =5000 K
Feed Loss	0.60	dB	Temp.= 10 K
Receive Line Loss	1.40	dB	Temp.= 290 K
Receiver Temperature			360 K
System Noise Temperature	35.56	dB-K	3595.6 K at Receiver Input
Effective G/T	18.94	dB/K	
Received Carrier Level	-117.20	dBW	At Receiver Input
Boltzmann's Constant	-228.60	dBW/Hz-K	
Received C/No	75.84	dB-Hz	
ISI Degradation	0.00	dB	
Modem Loss	2.00	dB	
Data Rate	60.00	dB-Hz	1 Mb/s
Available Eb/No	13.84	dB	
Required Eb/No	10.50	dB	BER = 10^{-6}, uncoded
Coding Gain	0.00	dB	
Eb/No Margin	3.34	dB	

ACQUISITION ARCHITECTURE DESIGN

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ACQUISITION ASSUMPTIONS

1. GEO TDAS pointing error: $\pm 0.2^\circ$

2. LEO user pointing error: $\pm 2.0^\circ$

ACQUISITION

<u>Factors</u>

- Antenna sizes (large antennas have narrower beamwidths)
- Antenna pointing errors (spacecraft ephemeris plus antenna positioning)

<u>Methods</u>

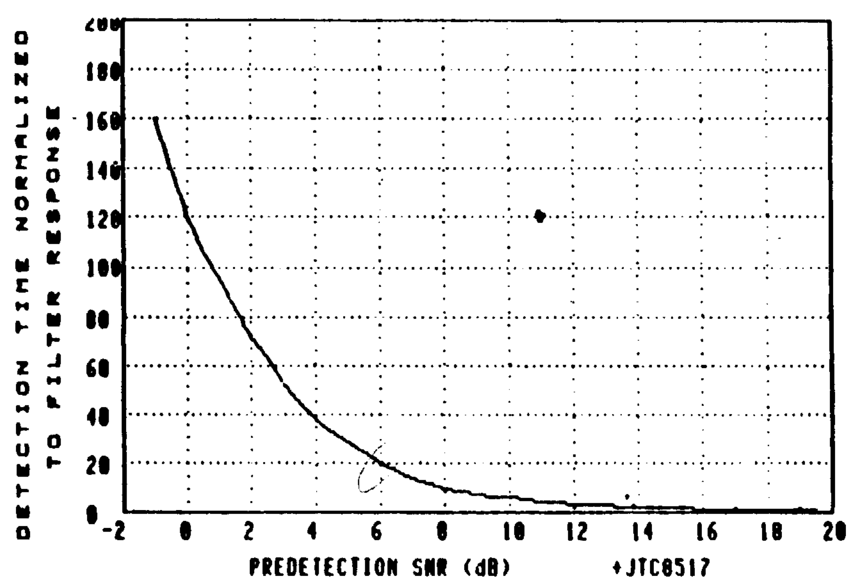
- Use comm antennas for acquisitions
- Use one auxiliary acquisition antenna for all initial acquisitions

<u>GEO-GEO Crosslink</u>

- Equal size antennas
- One antenna illuminates (transmits), other receives and searches area

ACQUISITION SIGNAL DETECTION TIME

FOR 99.9 % PROB. DET. and FALSE ALARM < 1 %



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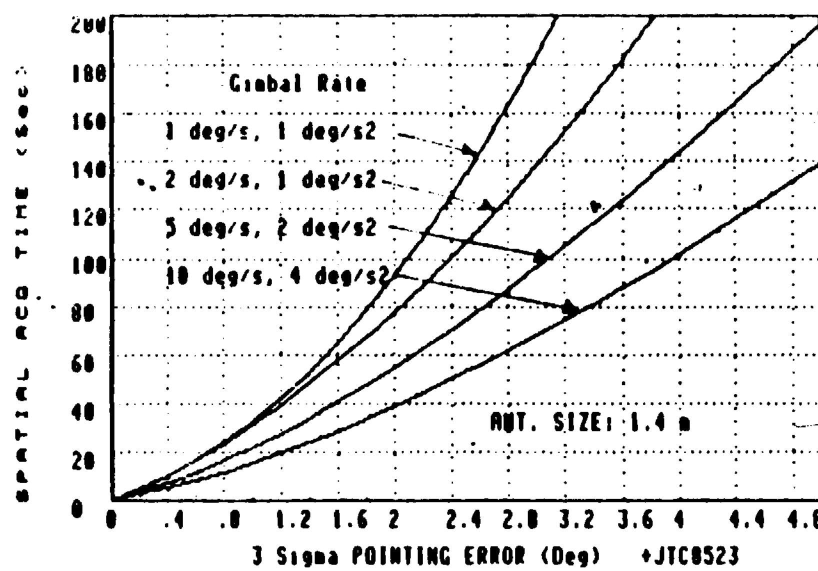
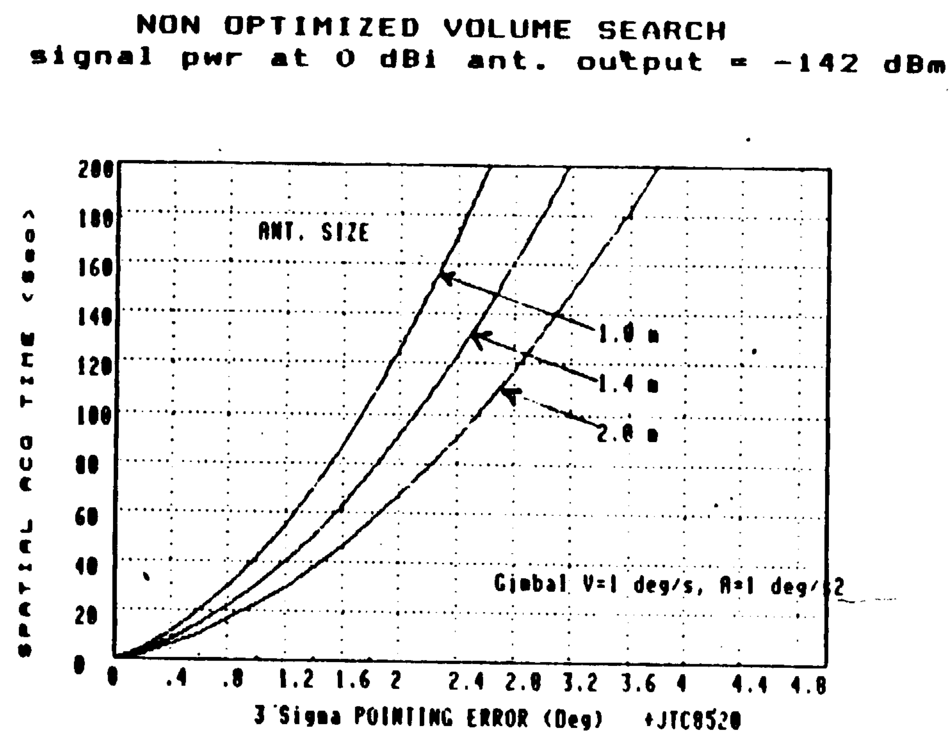
SPATIAL ACQUISITION TIME

NON OPTIMIZED VOLUME SEARCH
signal pwr at 0 dBi ant. output = -142 dBm



SPATIAL ACQUISITION TIME



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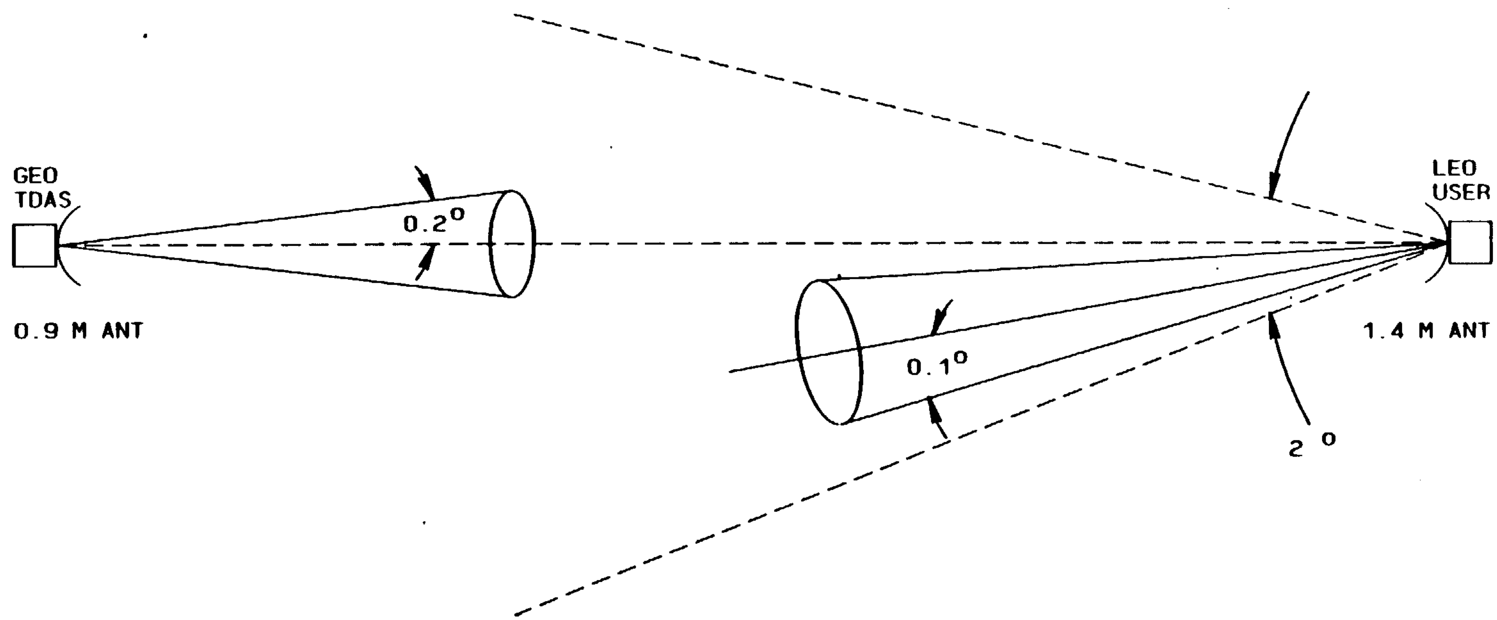
ACQUISITION STRATEGIES

1. User initially illuminate TDAS
   - High gain high accuracy antenna.
   - Low gain antenna large transmitter.
   - Auxilary low gain acquisition antenna.
2. TDAS Illuminates LEO
   - Moderate gain antenna.
   - Low gain auxilary antenna.
   - High gain antenna with multiple acquisition attempts.

SELECTED APPROACH

- o Auxilary acquisition antenna adds complexity.
- o Single acquisition antenna precludes concurrent acquisitions.
- o Reduced size of TDAS ISL antenna increases EIRP requirement of user.
- o System flexibility and simplicity justifies the increased user EIRP.

SELECTED APPROACH



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GEO-GEO ACQUISITION

Either one of the 2 GEO can acquire the other as follows:

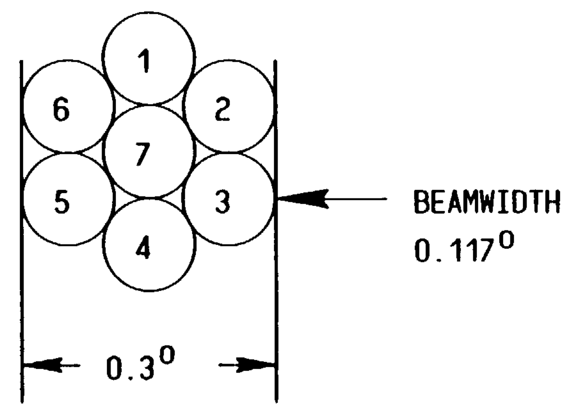
1. GEO 1 - rotates its axis to form 7 sequential main lobes, as shown

2. GEO 2 - Perform optimized spatial search requiring 4 sec. for each of GEO #1 main lobe.

   - Worst case total search time is 27 sec.

3. GEO 2 - Signal GEO #1 of acquisition

4. Both GEO #1 and GEO #2 initiate monopulse tracking



60 GHz LEO-GEO ACQUISITION ANALYSIS

Target LEO Vehicle Paramteters

o	3σ azimuth uncertainty	$\pm 2.0^{\circ}$
o	3σ elevation uncertainty	$\pm 2.0^{\circ}$
o	Nominal acquisition carrier frequency	57.8 GHz
o	3σ frequency error	± 1.8 MHz
o	Nominal signal level referenced at receiver input	-117.2 dBW
o	Maximum LEO vehicle velocity	0.045°/s

60 GHz LEO-GEO ACQUISITION ANALYSIS (CONTINUED)

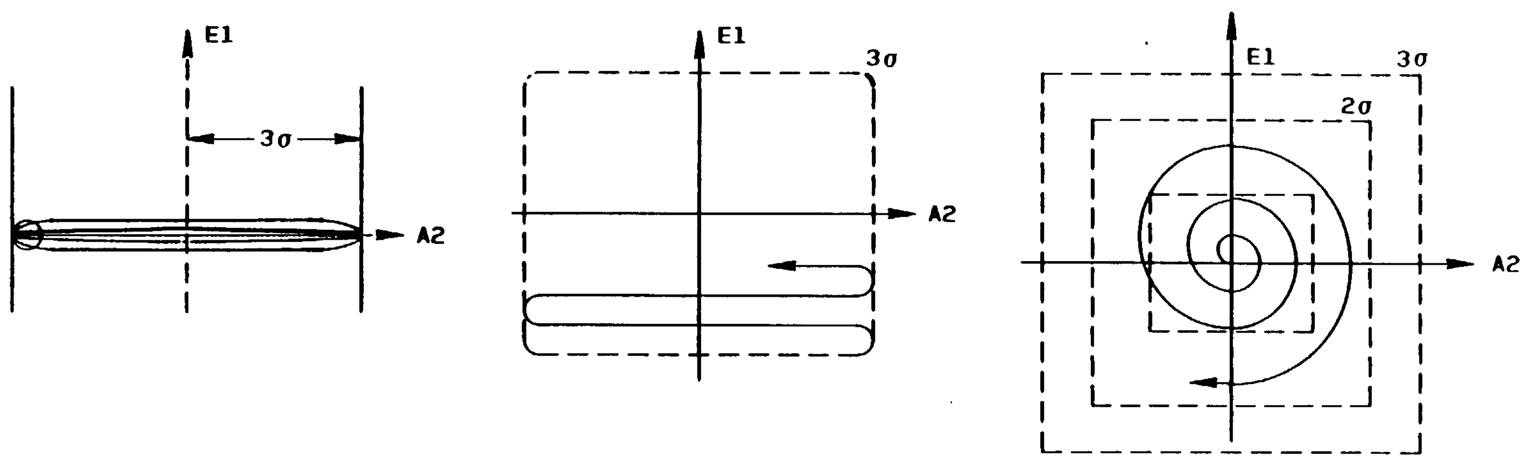
ACQUISITION CONDITIONS

o Input signal level	-117.2 dBW
o Acquisition antenna gain (1.4M)	56.6 dB
o System noise temperature (3417K)	35.56 dB-K
o Effective C/kT	75.84 dB/Hz
o Effective 3 dB C/kT	72.84 dB/Hz
o Effective 3 dB beamwidth	0.259^{o}
o Rated azimuth antenna velocity	$1.0^{o}/s$
o Rated azimuth antenna acceleration	$1.0^{o}/s^{-2}$
o Rated elevation antenna velocity	$1.0^{o}/s$
o Rated elevation antenna acceleration	$1.0^{o}/s^{-2}$

SPATIAL ACQUISITION

SPATIAL SEARCH APPROACH

(A) TACQ=50 TIME SEC.	(B) TACQ=82 SEC.	(C) TACQ=44 SEC.
SECTOR SEARCH	VOLUME SEARCH	OPTIMIZED SEARCH
• SEARCH ONE DIMENSION(AZ) UNTIL TARGET CROSSES THE OTHER (EL)	• SEARCH 2-D SPACE DEFINED BY 3σ UNCERTAINTIES IN AZIMUTH AND ELEVATION	• SEARCH 2-D SPACE DEFINED IN (B) EXCEPT THE SEARCH START AT MOST LIKELY SPACE



ACQUISITION EQUATIONS

$$P_{ACQ} = P_{VISIBILITY} \cdot P_{DETECTION}$$

WHERE $P_{VISIBILITY} = P(3\sigma)_{AZIMUTH} \cdot P(3\sigma)_{ELEVATION} \cdot P(3\sigma)\text{FREQ.}$

$$P_{DETECTION} = \sum_{i=2}^{N} \binom{N}{i} Pd^{i} (1 - Pd)^{N-i}$$

WITH

$$P_{FA} = \sum_{i=2}^{N} \binom{N}{i} Pf^{i} (1 - Pf)^{N-i}$$

WHERE
- Pd IS THE NONCOHERENT DETECTION PROBABILITY : ASSUMED 0.99
- Pf IS THE FALSE ALARM RATE : ASSUMED 0.001

$$Pd = f(Pf, \gamma, SNR, k)$$

k — NUMBER OF INTEGRATIONS REQUIRED

γ — THRESHOLD FOR GIVEN Pf AND k

(IF PREDETECTION SNR $<$17 dB, INTEGRATION IS REQUIRED FOR OUR LINK DESIGN)

SEARCH CASE 1: SECTOR SCAN ANALYSIS

o Maximum azimuth antenna scan rate	1.0/s
o Acquisition bandwidth	4000 KHz
o Predetection SNR	6.8 dB
o Acquisition time	50.5s
o Probability of visibility	99.3266%
o System availability (assumed)	100.0000%
o Number of verifications	3
o Number of integrations	16
o Probability of detection	99.9702%
o Probability of false alarm	0.0003%
o Probability of acquisition	99.297%

SEARCH CASE 2: VOLUME SEARCH ANALYSIS

o Maximum azimuth antenna scan rate	1.0^{o}/s
o Acquisition bandwidth	4000 kHz
o Predetection SNR	6.8 dB
o Acquisition time	80.5 s
o Probability of visibility	99.1923 %
o System availability (assumed)	100.0000 %
o Number of verifications	3
o Number of integrations	16
o Probability of detection	99.9702 %
o Probability of false alarm	0.0003 %
o Probability of acquisition	99.16274 %

SEARCH CASE 3: OPTIMIZED SEARCH ANALYSIS

o Maximum azimuth antenna scan rate	$1.0^{o}/s$
o Acquisition bandwidth	4000 kHz
o Predetection SNR	6.8 dB
o Acquisition time	42.9 s
o Probability of visibility	99.1923 %
o System availability (assumed)	100.0000 %
o Number of verification	3
o Number of integrations	16
o Probability of detection	99.9702 %
o Probability of false alarm	0.0003 %
o Probability of acquisition	99.16274 %

TRACKING ASSUMPTIONS

- Single Channel Monopulse
- Gimbals Corrected For Platform Perturbation Rates
- LEO Maximum Orbital Altitude - 5000 km
- C/KT - GEO/LEO 87.7 dB-Hz
-GEO/GEO 99.3 dB-Hz
- Tracking Receiver Bandwidth - 4 MHz

TRACKING ANALYSIS:

- Dynamic Lag and Thermal Noise Errors Evaluated
- Servo Bandwidths Optimized for Minimum Tracking Loss

TRACKING CONCLUSIONS

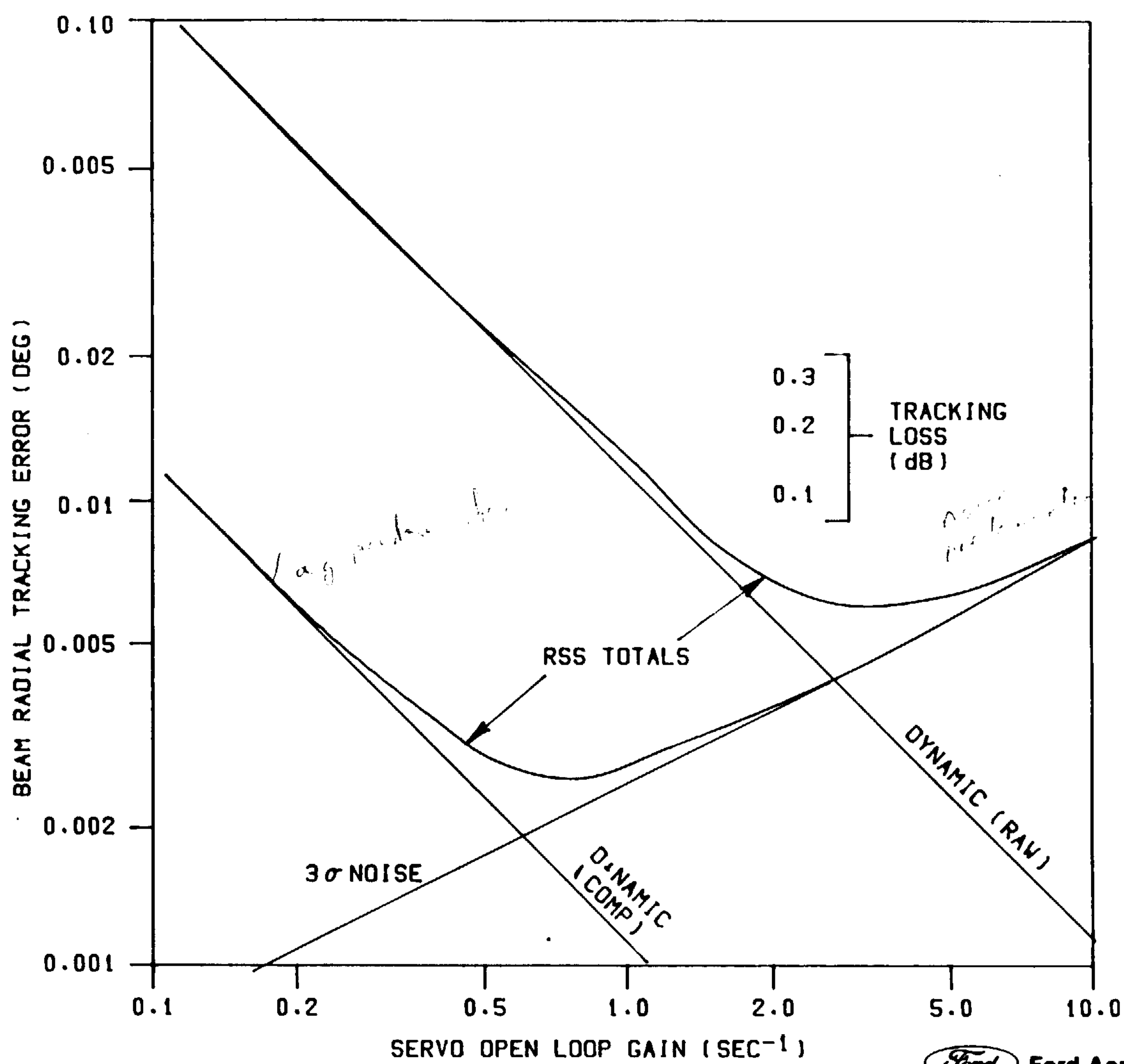
GEO-LEO:

Can achieve pointing accuracy of 0.02 degrees with 2Hz antenna structure

GEO-GEO:

With platform compensation scheme, pointing accuracy of 0.005 degrees is possible resulting in pointing loss <0.1 dB

AUTOTRACKING ACCURACY - GEO/LEO



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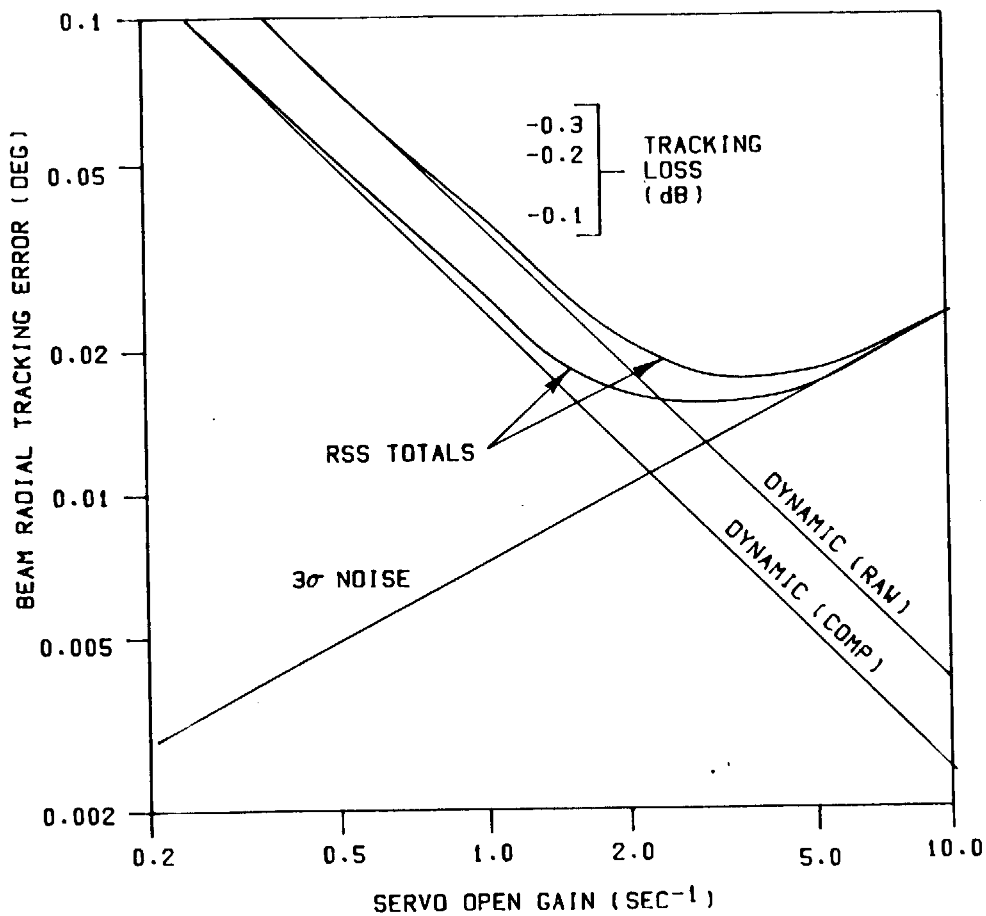
AUTOTRACKING ACCURACY - GEO/GEO



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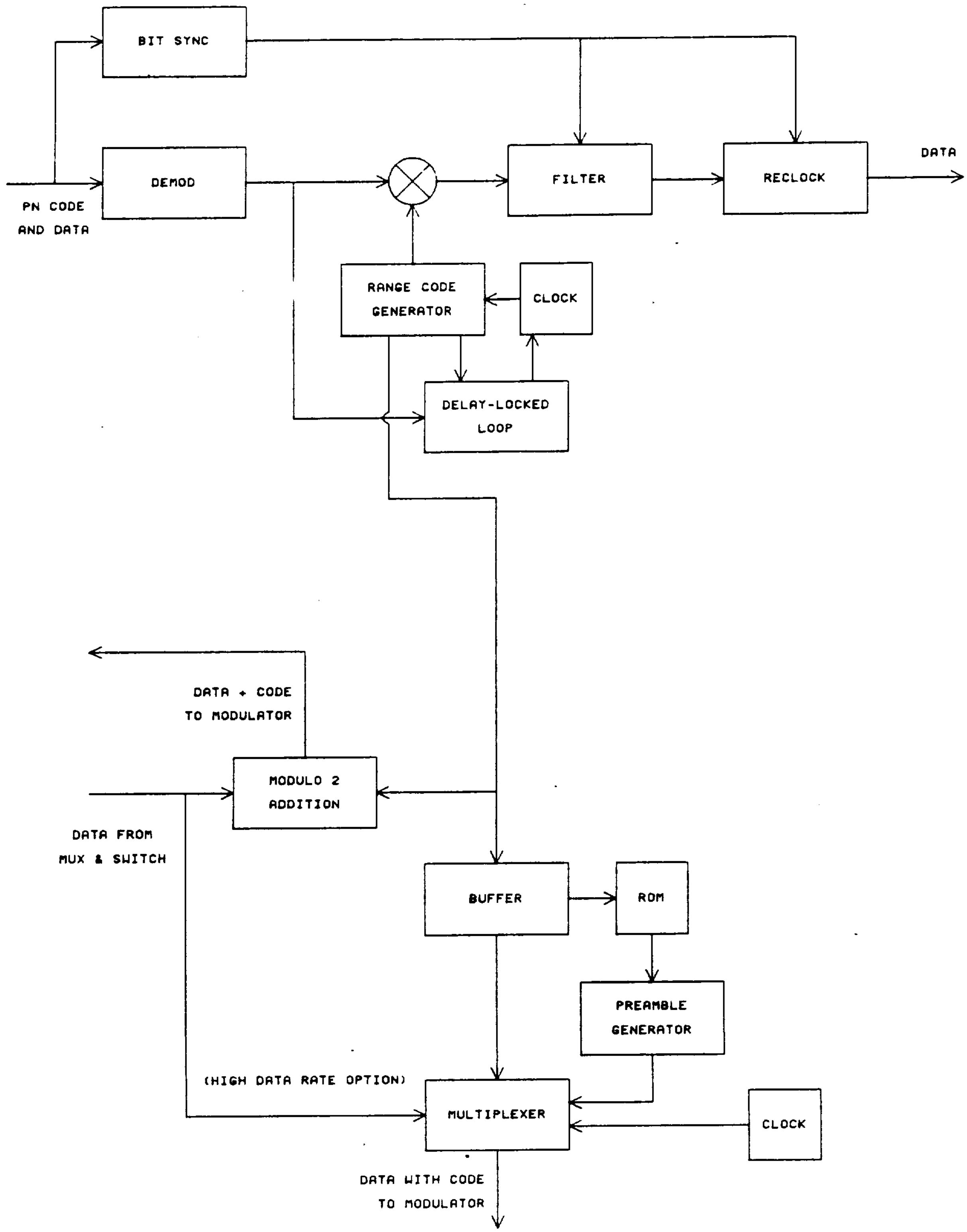
RANGING CONCEPT

- PN Sequence Time Delay Measurement Using 3 MChip Range Code.
- Return Code Modulation Method is a Function of USAT Data Rate.
- Coherent turn-around for Range Rate.

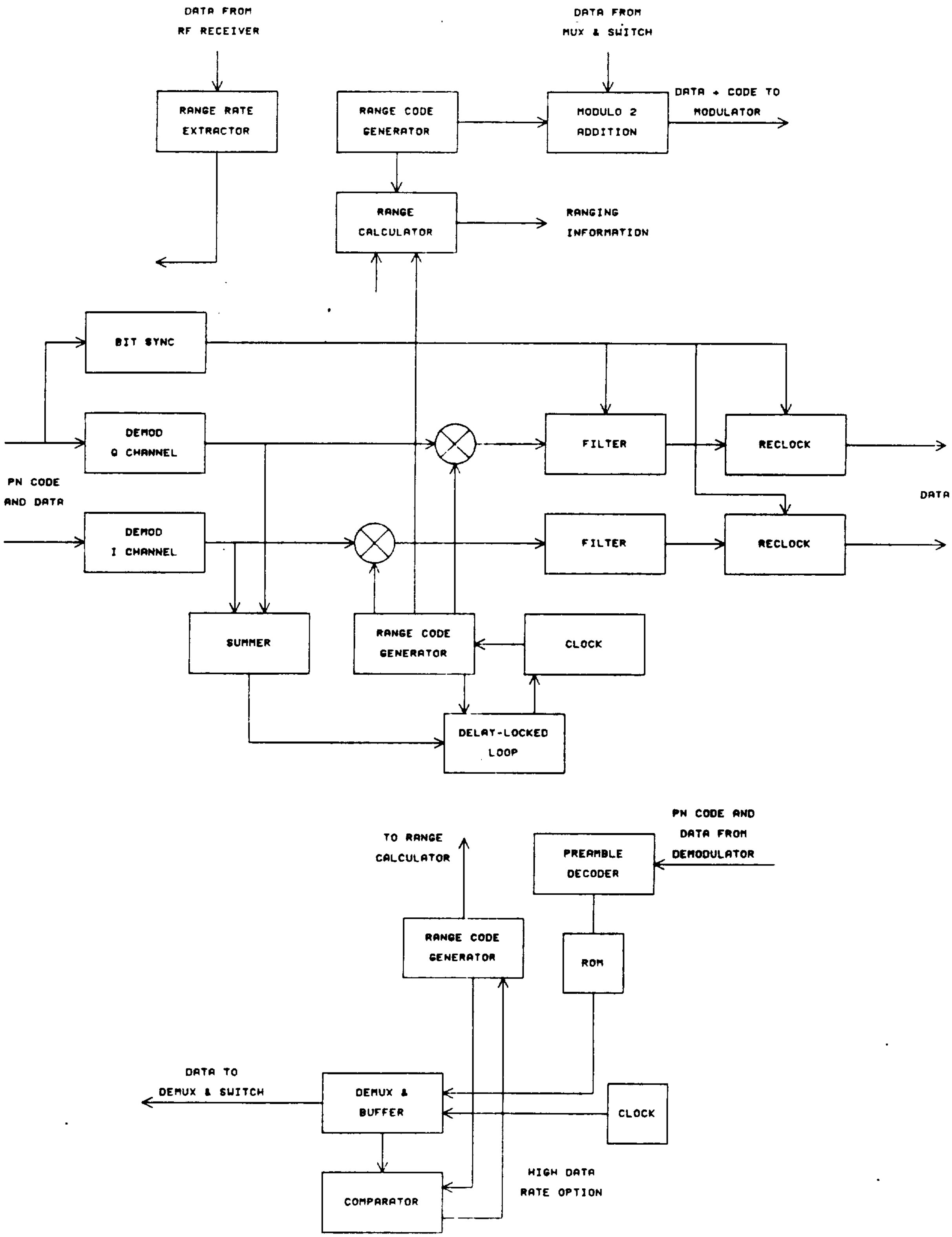
RANGING ACCURACY:

- 3 MChip Rate Allows 5-meter range accuracy, assuming 5% code tracking error.

- Range rate requirement of ± 0.2 cm/sec requires 1 second stability of 1×10^{-10}.



LEO RANGING SUBSYSTEM



GEO RANGING SUBSYSTEM

POLARIZATION ASSIGNMENTS:

GEO #1 to GEO #2	Transmit . . . . RHCP
GEO #1 from GEO #2	Receive. . . . . LHCP
GEO #2 to GEO #1	Transmit . . . . LHCP
GEO #2 from GEO #1	Receive. . . . . RHCP
GEO to LEO	Transmit . . . . RHCP
GEO from LEO	Receive. . . . . LHCP
LEO to GEO	Transmit . . . . LHCP
LEO from GEO	Receive. . . . . RHCP

PHASE LOCK LOOP TRACKING PERFORMANCE

ONCE ACQUISITION IS ACHIEVED, CARRIER ACQUISITION IS QUITE EASY (AND DEPENDS ON MODULATION TECHNIQUE SELECTED):

- o CARRIER RECOVERY (FOR BPSK BASELINE)

  THE RMS PHASE JITTER IS LESS THAN 1^{o} IN A 10 kHz PLL

- o MEAN TIME OF LOSING LOCK:

$$T_L = \frac{0.95}{10\ \text{kHz}} \exp[\pi \cdot SNR_{PLL}] >> 10^9 \text{sec}$$

POWER AND WEIGHT

	EQUIPMENT	STRUCTURE
o TDAS (GEO-LEO)	415 lbs 541 watts	102 lbs
o TDAS (GEO-GEO)	157 lbs 244 watts	30 lbs
o USAT	97 lbs 195 watts	

COMPONENTS POWER, WEIGHT AND SIZE (GEO-GEO)

GEO-GEO EQUIPMENT	Qty	PER UNIT DATA Weight lbs.	Power W	Size in x in x in	Redundancy
Receiver (RF Portion)	1	4.3	28	5 x 4 x 2 1 x 3 x 3/4	1
2 GBPS Demodulator (QPSK)	1	3	6	3 x 4 x 2	1
QPSK Modulator & L.O.	1	5	24	3 x 4 x 1 5 x 4 x 2	1
Transmitter (10W)	1	1.6	111	14 x 5 x 1.5	1
Feed Assembly	1	3.5	-	4 x 4 x 18	-
Antenna (3.2 m)	1	60.5	-	3.2m x 3.2 x .9	
300 MBPS QPSK Demodulator	1	3	6	3 x 4 x 2	1
Gimbal Subsystem	1	28	9*, (32**)	14 x 13.5 x 11	-
Gimbal Drive Electronics	1	5	6	8.5 x 2.6 x 5.7	1
Acquisition & Tracking Receiver	1	1.2	4	3 x 6 x 2	1
TOTAL PER OPERATIONAL SYSTEM		115.1	194		
TOTAL PER SPACECRAFT (PAYLOAD)		138.2			
DC/DC Converter		4	49		2
Antenna System Control Electronics	1	3.5	1.0	112 in.^{3}	1
6 Antenna Controller	1	0.5	0.1	4 x 8 x 1/2	6
1 Antenna Control Microprocessor	1	0.5	0.4	4 x 8 x 1/2	1
TOTAL PER OPERATIONAL SYSTEM		3.5	1.0		
TOTAL PER SPACECRAFT (CONTROLLER)		7.0			
TOTAL PER SPACECRAFT		157.2	244.0		
* Average **Peak					

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COMPONENTS POWER, WEIGHT AND SIZE (GEO-LEO)

GEO EQUIPMENT	Qty	PER UNIT DATA Weight lbs.	Power W	Size in x in x in	Redundancy
LEO-GEO Receiver (RF Portion)	1	4.3	28	5 x 4 x 2 1 x 3 x 3/4	1
QPSK Demodulator & FEC Decoder	1	4	16	3 x 6 x 2	1
GEO Ranging Subsystem	1	0.5	0.6	4.5 x 4.5 x 3/4	-
BPSK Modulator (1Mb/s) & L.O.	1	4.1	18.2	3 x 4 x 1 5 x 4 x 2	1
Transmitter (0.6 W)	1	0.3	6.3	3.3 x 2 x 1	1
Feed Assembly	1	3.3	-	4 x 4 x 18	-
Antenna (0.9 m)	1	7.3	-	0.9 m x .9 x .3	36 x 36 x 1
Gimbal Subsystem	1	28	9*, (32**)	14 x 13.5 x 11	-
Gimbal Drive Electronics	1	5	4.5	8.5 x 2.6 x 5.7	1
Acquisition & Tracking Receiver	1	1.2	4	3 x 6 x 2	1
TOTAL PER OPERATIONAL SYSTEM PER USAT		58.0	86.6		
TOTAL PER USAT (PAYLOAD)		76.9			
TOTAL PER SPACECRAFT (5 PAYLOADS)		384.5	483.0		
DC/DC Converter		10	108.0		2
TOTAL PER SPACECRAFT		414.5	541.0		
* Average ** Peak					

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LEO EQUIPMENT	Qty	PER UNIT DATA Weight lbs.	 Power W	 Size in x in x in	Redundancy
GEO-LEO Receiver (RF Portion)	1	4.3	28	5 x 4 x 2 1 x 3 x 3/4	1
BPSK Demodulator(1 Mb/s)	1	2	2	3 x 4 x 2	1
LEO Ranging Subsystem	1	0.5	0.6	4.5 x 4.5 x 3/4	-
QPSK Modulator & L.O. & FEC Encoder	1	5	24	3 x 4 x 1 5 x 4 x 2	1
Transmitter (7.5 W)	1	1.6	83	14 x 5 x 1.5	1
Feed Assembly	1	3.3	-	4 x 4 x 18	-
Antenna (1.4 m)	1	12.8	-	1.4m x 1.4 x .42	55 x 55 x 16.5
Gimbal Subsystem	1	28	9* (32**)	14 x 13.5 x 11	-
Gimbal Drive Electronics	1	5	4.5	8.5 x 2.6 x 5.7	1
Acquisition & Tracking Receiver	1	1.2	4	3 x 6 x 2	1
TOTAL PER OPERATIONAL SYSTEM		63.7	155.1		
TOTAL PER SPACECRAFT (PAYLOAD)		82.8			
DC/DC Converter		4	39.0		2
Antenna System Control Electronics					
1 Antenna Controller	1	0.5	0.1	4 x 8 x 1/2	1
1 Antenna Control Microprocessor	1	0.5	0.4	4 x 8 x 1/2	1
TOTAL PER OPERATIONAL SYSTEM		1.0	0.5		
TOTAL PER SPACECRAFT (CONTROLLER)		2.0			
TOTAL PER SPACECRAFT		96.8	194.6		

* Average
**Peak

REDUNDANCY

- Electronic components are doubly redundant except DC/DC converter, which is triply redundant, and ranging subsystem, which is non-redundant.
- Antennas, gimbals and feed assembly are non-redundant.
- Gimbal drive and antenna control system have redundant electronics.

TYPICAL TELEMETRY AND COMMAND LIST

Unit: Command

Commands	Telemetry
Command address (selects unit to process data)	Command verification
Critical command enable/disable	Execute flag
Data load to controller	Stored and sequence readout
Stored program time lag	

Unit: Telemetry

Commands	Telemetry
Unit on/off	Frame sync
Dewll mode select	Subframe counter
Dwell word(s) select	Dwell word i.d.
	Spacecraft i.d.
	Telemetry unit on/off status

Unit: Transmitter

Commands	Telemetry
Unit on/off	On/off status
Mod index select	Mod index selected
Mod source select	Mod source selected

Unit: Receiver

Commands	Telemetry
	Phase lock loop lock status
	Phase lock loop stress
	Receiver AGC voltage

Unit: System Controller and Gimbal Drive

Commands	Telemetry
Unit on/off	On/off status
Track auto/manual	Mode, auto scan/manual slew
Slew, manual pitch	Controller data dump
Slew, manual yaw	Pitch Drive to motor
Pitch, slew limit	Yaw drive to motor
Yaw slew limit	
Auto scan select	
Data load	

ON-ORBIT TEST

- o Stability of GEO-GEO Link allows time for careful complete checkout of satellite operation.
- o Short LEO contact times and diversity of users preclude rapid and accurate performance verification.
- o STS-mountable test set would provide optimum checkout of ISL equipment.

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CHANNELIZED CROSSLINKS

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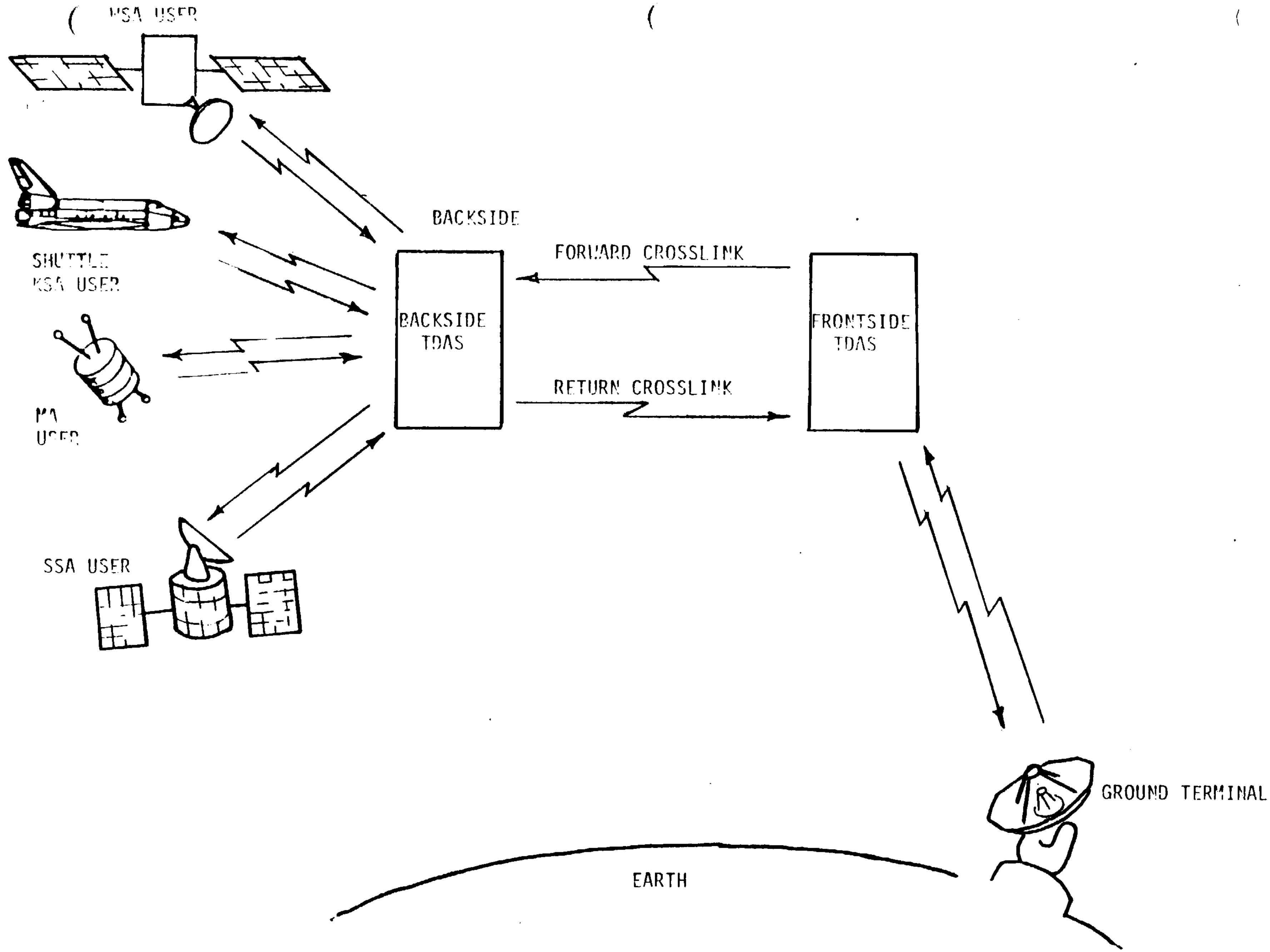
CHANNELIZED 60GHz INTERSATELLITE CROSSLINK

- Modulate/Demodulate Links
  - WSA Forward and Return Links
  - LSA Forward and Return Links
  - SMA Forward and Return Links
- Bent-Pipe Links
  - KSA Forward and Return Links
  - SSA Forward Return Links
  - TT&C Forward and Return Links



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CHANNELIZED 60 GHz CROSSLINK CHARACTERISTICS SUMMARY
RETURN LINKS

LINK	TYPE	DATE RATE	MOD	POWER AMP	BER	MARGIN
WSA 1	MOD/DEMOD	300 MBPS	QPSK	2.5 W	10^{-6}	1.48 dB*
WSA 2	MOD/DEMOD	300 MBPS	QPSK	2.5 W	10^{-6}	1.70 dB*
WSA 3	MOD/DEMOD	300 MBPS	QPSK	2.5 W	10^{-6}	1.93 dB*
WSA 4	MOD/DEMOD	300 MBPS	QPSK	2.5 W	10^{-6}	2.14 dB*
WSA 5	MOD/DEMOD	300 MBPS	QPSK	2.5 W	10^{-6}	2.48 dB*
LSA 1	MOD/DEMOD	300 MBPS	QPSK	2.5 W	10^{-6}	2.07 dB*
LSA 2	MOD/DEMOD	300 MBPS (1000 MBPS)	QPSK	2.5 W	10^{-6}	2.28 dB*
LSA 3	MOD/DEMOD	300 MBPS	QPSK	2.5 W	10^{-6}	2.49 dB*
LSA 4	MOD/DEMOD	100 MBPS	QPSK			
SMA 1	MOD/DEMOD	0.05 MBPS	QPSK			
o	o	o		1.0 W	10^{-6}	1.41 dB*
SMA 10	MOD/DEMOD	0.05 MBPS	QPSK			
TT&C	MOD/DEMOD	0.01 MBPS	QPSK			
SSA 1	BENT PIPE	12 MBPS	QPSK	1.0 W	10^{-5}	-0.30 dB**
SSA 2	BENT PIPE	12 MBPS	QPSK	1.0 W	10^{-5}	-0.30 dB**
KSA 1	BENT PIPE	300 MBPS	QPSK	4.0 W	10^{-5}	-0.68 dB**
KSA 2	BENT PIPE	300 MBPS	QPSK	4.0 W	10^{-6}	-0.68 dB**
TT&C	BENT PIPE	0.01 MBPS		0.1 W	10^{-5}	14.14 dB **

*Backside to frontside crosslink performance only. Does not include given user link or downlink degradation

**Calculated at ground terminal based on User Link/Down Link parameters given in "TDRSS Telecommunications Performance and Interface Document" SE-09 12 March 1984.

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CHANNELIZED 60 GHz CROSSLINK CHARACTERISTICS SUMMARY

FORWARD LINKS

LINK	TYPE	DATA RATE	MOD.	POWER AMP	BER	MARGIN
WSA 1	MOD/DEMOD	1 MBPS	QPSK			
WSA 2	MOD/DEMOD	1 MBPS	QPSK			
WSA 3	MOD/DEMOD	1 MBPS	QPSK			
WSA 4	MOD/DEMOD	1 MBPS	QPSK			
WSA 5	MOD/DEMOD	1 MBPS	QPSK	1.0 W	10^{-6}	2.93 dB*
SMA 1	MOD/DEMOD	0.01 MBPS	QPSK			
SMA 2	MOD/DEMOD	0.01 MBPS	QPSK			
LSA	MOD/DEMOD	50 MBPS	QPSK		P/N	
SSA 1	BENT PIPE	0.3 MBPS	QPSK	0.025 W	22.86 dB*	
SSA 2	BENT PIPE	0.3 MBPS	QPSK	0.025 W	22.86 dB*	
KSA 1	BENT PIPE	25 MBPS	QPSK	2.0 W	23.34 dB*	
KSA 2	BENT PIPE	25 MBPS	QPSK	2.0 W	23.34 dB*	
TT&C	BENT PIPE	0.01 MBPS		0.1 W	43.91 dB*	

*Frontside to Backside crosslink performance only. Does not include user link or up link degradations.

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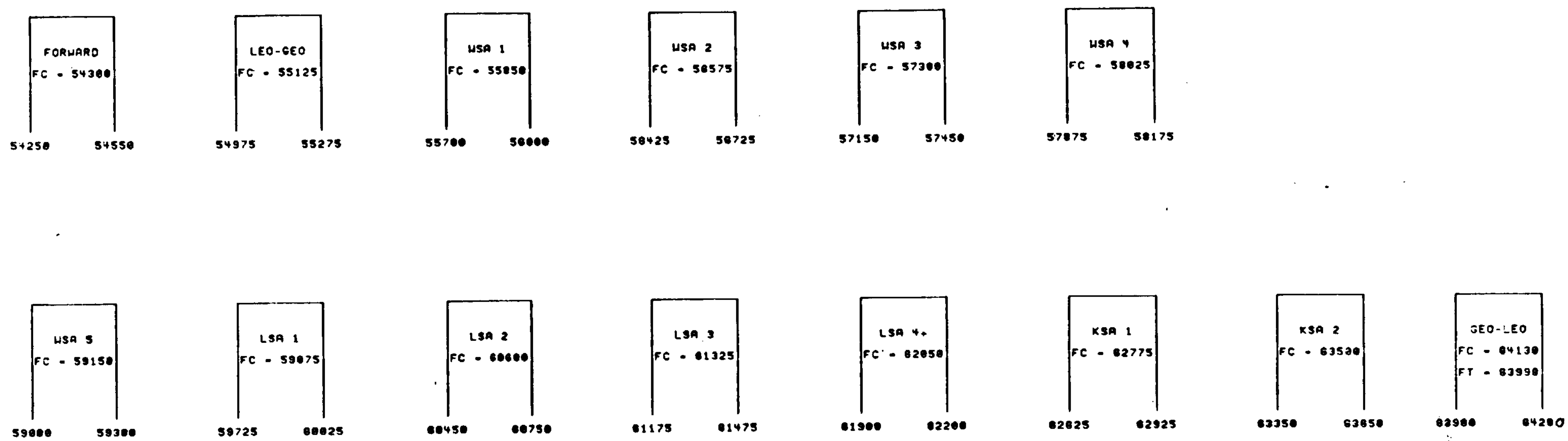

FREQUENCY PLAN

CHANNELIZED 60 GHZ INTERSATELLITE CROSSLINK

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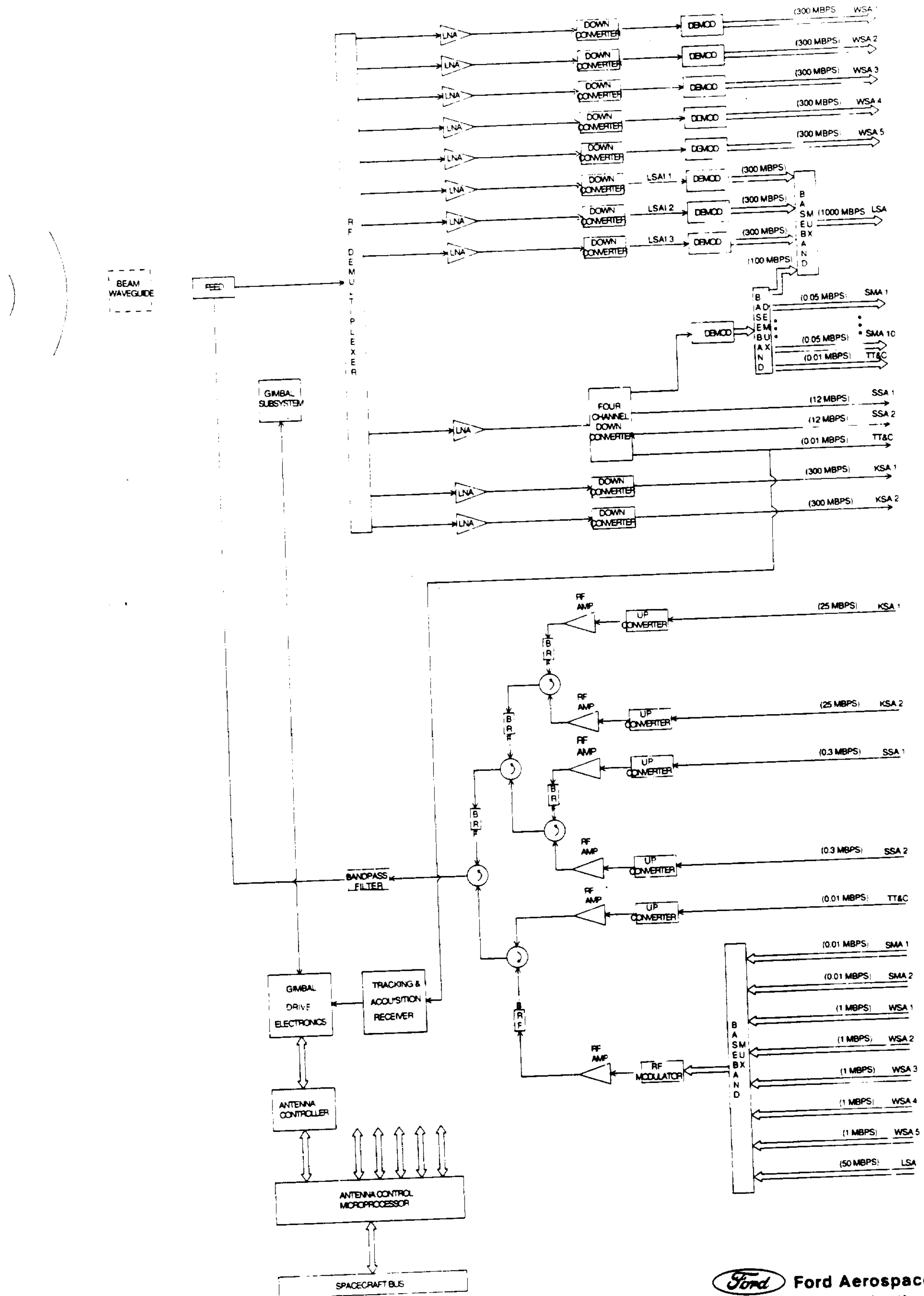

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FRONTSIDE SATELLITE EQUIPMENT

CHANNELIZED 60 GHZ INTERSATELLITE CROSSLINK

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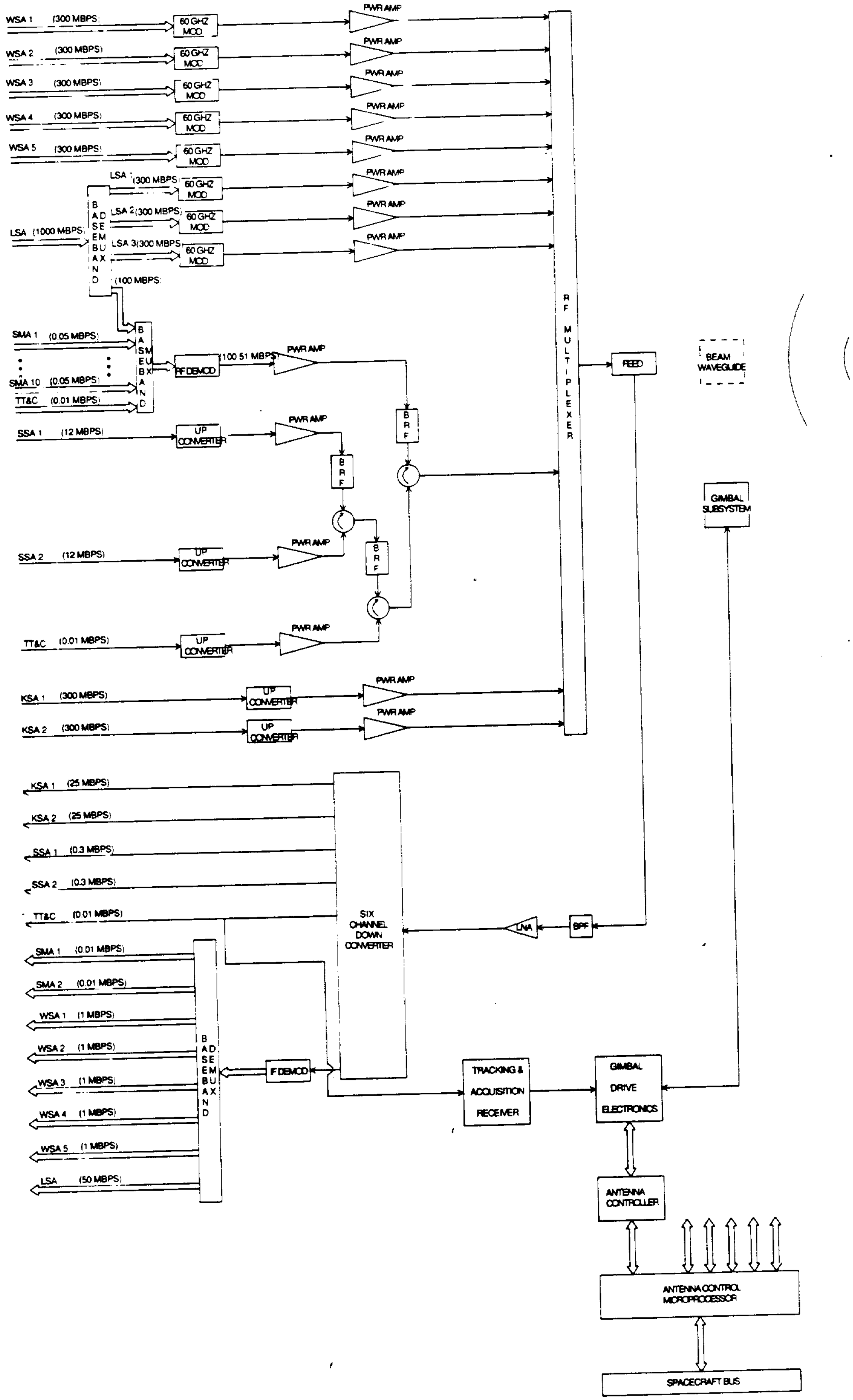

BACKSIDE SATELLITE EQUIPMENT

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CHANNELIZED 60 GHZ INTERSATELLITE CROSSLINK

ORIGINAL PAGE IS OF POOR QUALITY

CHANNELIZATION

- O 300 MHz CROSS LINK CHANNELS WORK WELL WITH THE DATA RATES OF THE VARIOUS SERVICES

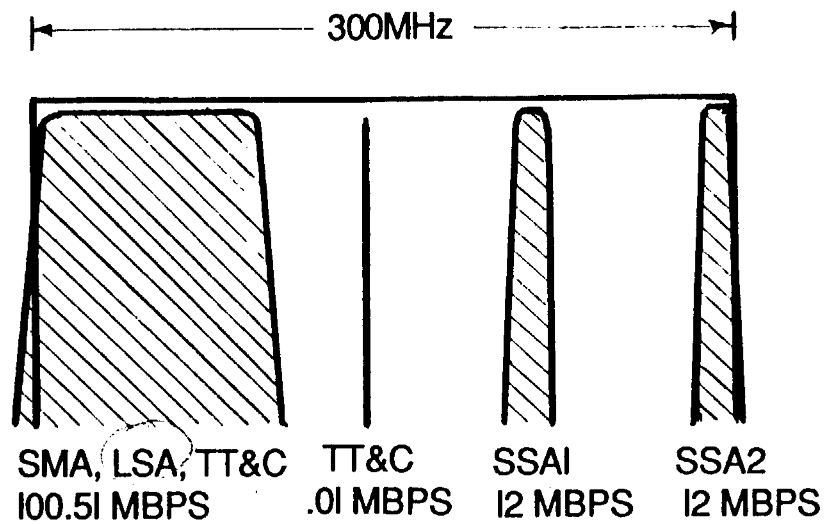
- O 300 MHz AT 60 GHz IS NEAR THE MINIMUM BANDPASS FILTER BANDWIDTH THAT CAN BE ACHEIVED WITH REASONABLE LOSS, FABRICATION TOLERANCES, AND TEMPERATURE STABILITY

(FOR EXAMPLE: A 60 GHz BANDPASS FILTER WITH A 300 MHz BANDWIDTH AND A Q OF 4000 WILL HAVE A LOSS OF 1.6 dB

A 60 GHz BANDPASS FILTER WITH A 150 MHz BANDWIDTH AND A Q OF 4000 WILL HAVE A LOSS OF 3.2 dB)

- O MULTIPLE LOWR DATA RATE LINKS THAT ARE MULTIPLEXED INTO A 300 MHz CHANNEL REQUIRE MULTIPLEXING SCHEMES THAT AVOID BANDPASS FILTERS AT 60 GHz

LSA4 CHANNEL UTILIZATION



Laser Single Access

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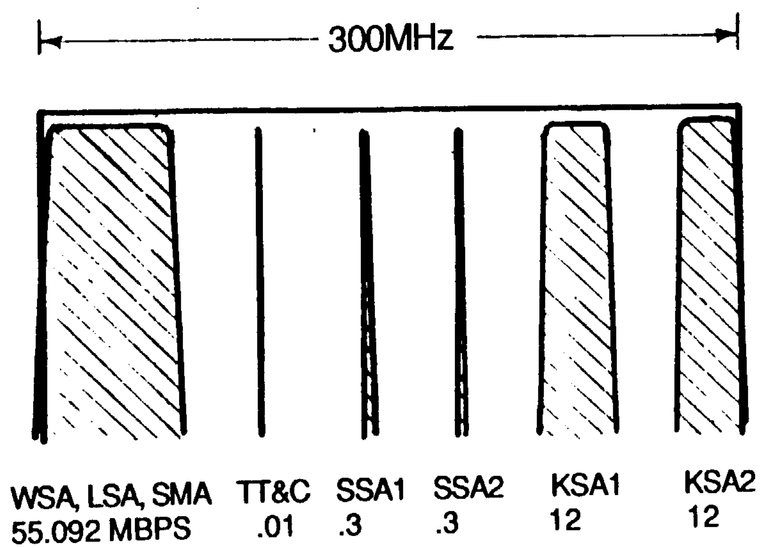
FORWARD CHANNEL UTILIZATION



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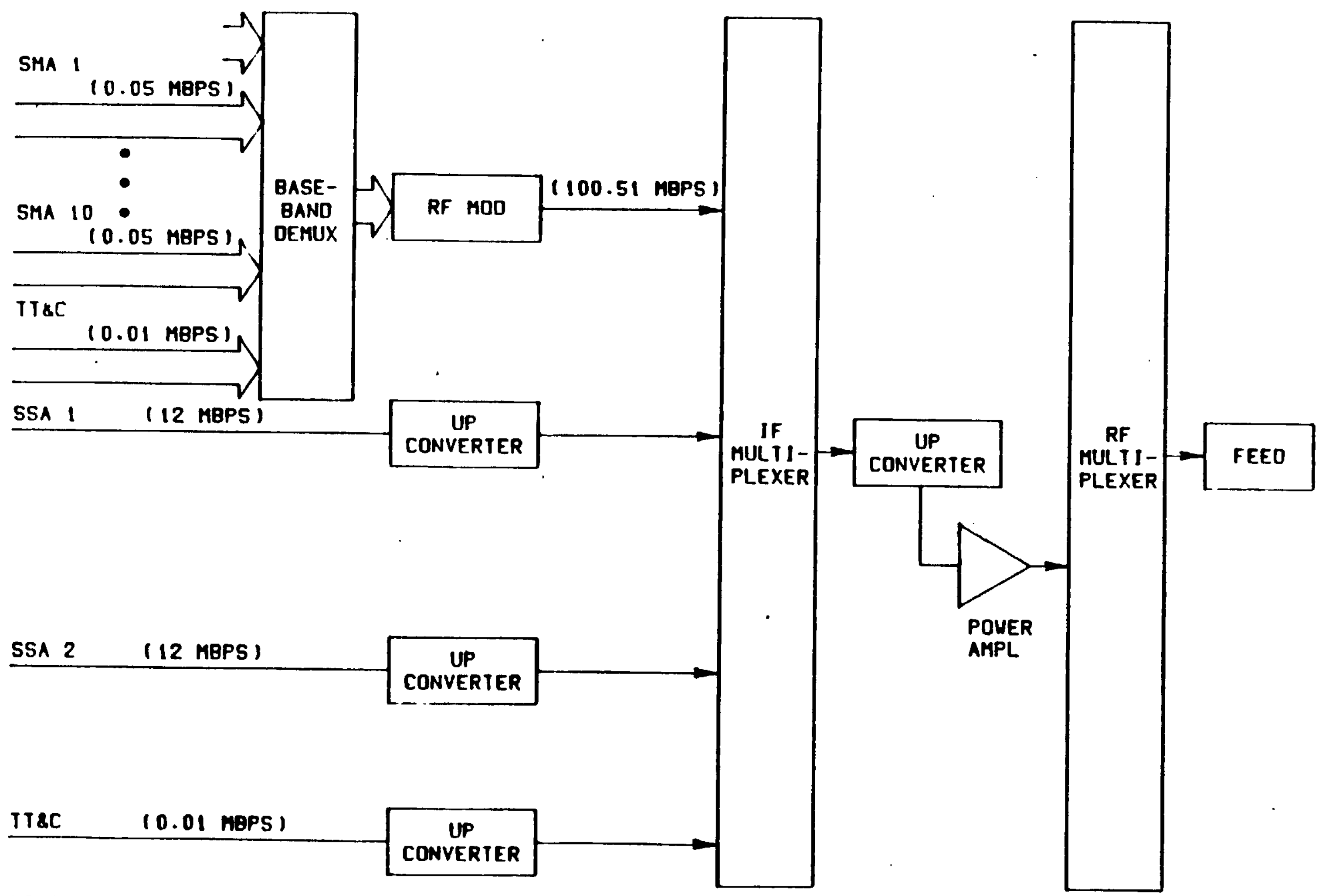
SIMPLEST MULTIPLEXING OF LSA4 CHANNEL



(THIS APPROACH REJECTED BECAUSE OF INTERMODULATION PROBLEMS IN THE UPCONVERTER AND POWER AMPLIFIER)

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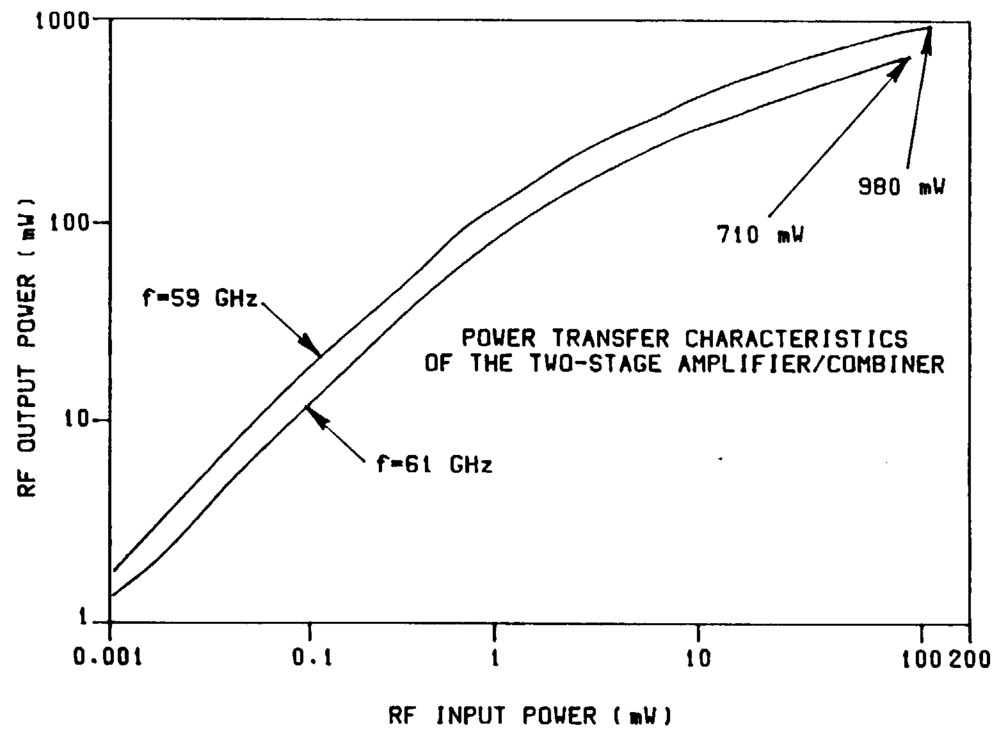
POWER TRANSFER CHARACTERISTIC OF COMPLETE TWO-STAGE IMPATT AMPLIFIER



Reference: H.J. Kuno and D.L. English, "Millimeter Wave IMPATT Power Amplifier/Combiner", IEEE Trans. Microwave Theory Tech., Vol. MTT-24, p.p. 758-767, Nov. 1976.

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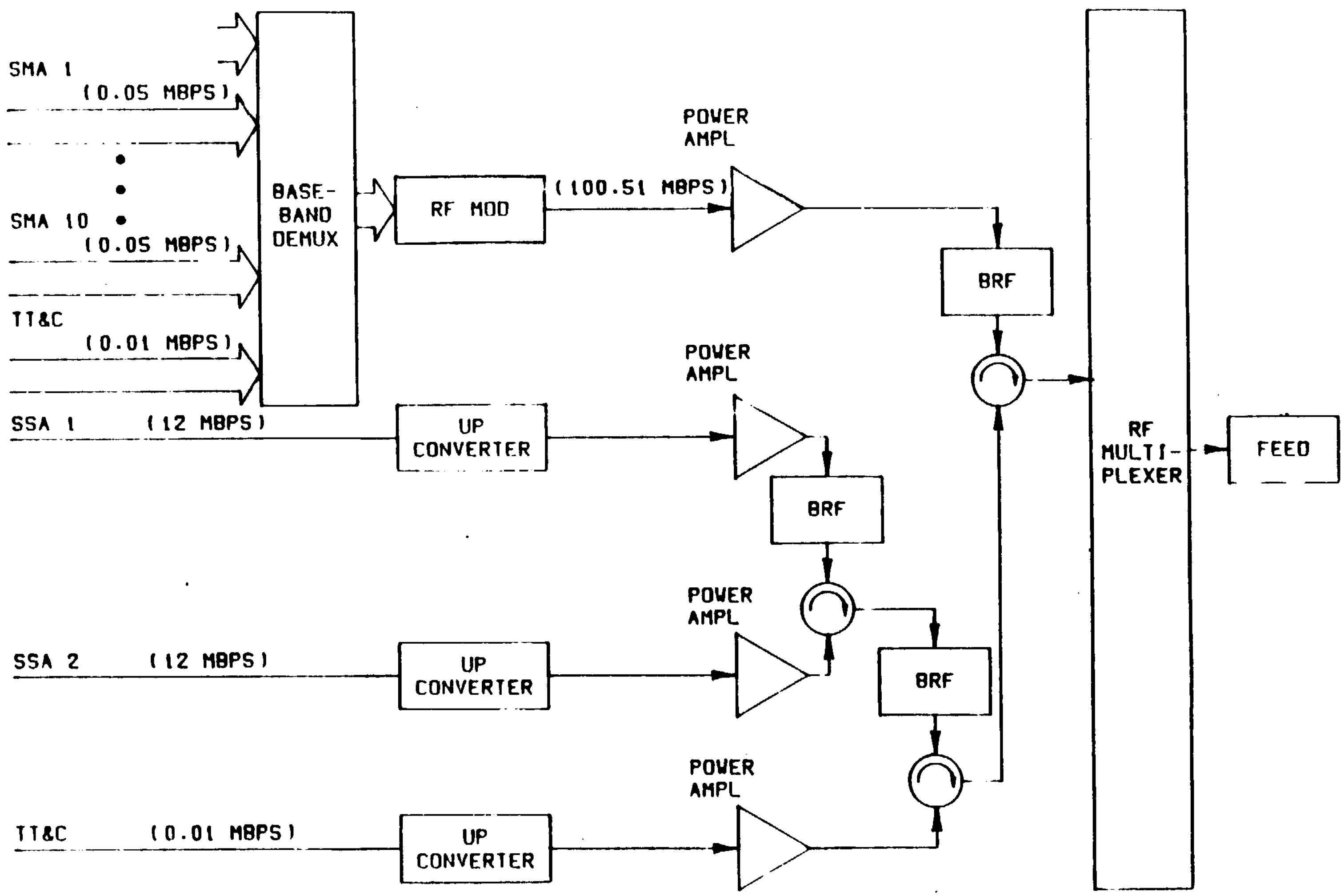
SELECTED APPROACH TO MULTIPLEXING LSA4 CHANNEL



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FEED AND NETWORK LOSS ASSESSMENT (1989)

(IN DB)

CHANNELIZED 60 GHZ CROSSLINK

	GEO/GEO	
ITEM	XMIT	RCVR
SWITCH	0.1	0.1
OUTPUT FILTER	1.6	
INPUT FILTER		1.6
COUPLER		0.2
SEPTUM POLARIZER	0.2	0.2
HORN COUPLER	0.1	0.1
WAVEGUIDE (0.25 M)	0.3	0.3
NETWORK TOTAL	2.3	2.5
BEAM WAVEGUIDE	0.6	0.6

WSA1 Channel without Sun Effect

Modulation: QPSK
Coding: None

Carrier Frequency = 55.8 GHz

Parameter	Value	Units	Remarks
Transmitting S/C Power	3.98	dBW	2.5 watts
Transmit Line Loss	2.30	dB	
Feed Loss	0.60	dB	
Transmitting Antenna Gain	63.40	dBi	3.2-m dish
EIRP	64.48	dBW	
Free Space Loss	225.78	dB	83,043 km
Pointing Loss	0.33	dB	0.02 degree
Polarization Loss	0.20	dB	
Tracking Loss	0.33	dB	0.02 degree
Net Path Loss	226.64	dB	
Receiving S/C Antenna Gain	63.40	dBi	3.2-m dish; Temp. = 10 K
Feed Loss	0.60	dB	Temp.= 10 K
Receive Line Loss	2.50	dB	Temp.= 290 K
Receiver Temperature			360 K
System Noise Temperature	26.92	dB-K	492.5 K at Receiver Input
Effective G/T	33.38	dB/K	
Received Carrier Level	-101.86	dBW	At Receiver Input
Boltzmann's Constant	-228.60	dBW/Hz-K	
Received C/No	99.82	dB-Hz	
CCI Degradation	0.00	dB	
ISI Degradation	1.07	dB	
Modem Loss	2.00	dB	
Data Rate	84.77	dB-Hz	300 Mb/s
Available Eb/No	11.98	dB	
Required Eb/No	10.50	dB	BER = 10^{-6}, uncoded
Coding Gain	0.00	dB	
Eb/No Margin	1.48	dB	

LSA1 Channel without Sun Effect

Modulation: QPSK
Coding: None

Carrier Frequency = 59.9 GHz

Parameter	Value	Units	Remarks
Transmitting S/C Power	3.98	dBW	2.5 watts
Transmit Line Loss	2.30	dB	
Feed Loss	0.60	dB	
Transmitting Antenna Gain	64.00	dBi	3.2-m dish
EIRP	65.08	dBW	
Free Space Loss	226.38	dB	83,043 km
Pointing Loss	0.33	dB	0.02 degree
Polarization Loss	0.20	dB	
Tracking Loss	0.33	dB	0.02 degree
Net Path Loss	227.24	dB	
Receiving S/C Antenna Gain	64.00	dBi	3.2-m dish; Temp. = 10 K
Feed Loss	0.60	dB	Temp.= 10 K
Receive Line Loss	2.50	dB	Temp.= 290 K
Receiver Temperature			360 K
System Noise Temperature	26.92	dB-K	492.5 K at Receiver Input
Effective G/T	33.98	dB/K	
Received Carrier Level	-101.26	dBW	At Receiver Input
Boltzmann's Constant	-228.60	dBW/Hz-K	
Received C/No	100.41	dB-Hz	
CCI Degradation	0.00	dB	
ISI Degradation	1.07	dB	
Modem Loss	2.00	dB	
Data Rate	84.77	dB-Hz	300 Mb/s
Available Eb/No	12.57	dB	
Required Eb/No	10.50	dB	BER = 10^{-6}, uncoded
Coding Gain	0.00	dB	
Eb/No Margin	2.07	dB	

LSA4 Channel without Sun Effect; Baseband Signals

Modulation: QPSK
Coding: None

Carrier Frequency = 62.0 GHz

Parameter	Value	Units	Remarks
Transmitting S/C Power	0.00	dBW	1.0 watts
Transmit Line Loss	3.80	dB	
Feed Loss	0.60	dB	
Transmitting Antenna Gain	64.20	dBi	3.2-m dish
EIRP	59.80	dBW	
Free Space Loss	226.69	dB.	83,043 km
Pointing Loss	0.33	dB	0.02 degree
Polarization Loss	0.20	dB	
Tracking Loss	0.33	dB	0.02 degree
Net Path Loss	227.55	dB	
Receiving S/C Antenna Gain	64.20	dBi	3.2-m dish; Temp. = 10 K
Feed Loss	0.60	dB	Temp.= 10 K
Receive Line Loss	2.50	dB	Temp.= 290 K
Receiver Temperature			360 K
System Noise Temperature	26.92	dB-K	492.5 K at Receiver Input
Effective G/T	34.18	dB/K	
Received Carrier Level	-106.65	dBW	At Receiver Input
Boltzmann's Constant	-228.60	dBW/Hz-K	
Received C/No	95.02	dB-Hz	
CCI Degradation	0.00	dB	
ISI Degradation	1.07	dB	
Modem Loss	2.00	dB	
Data Rate	80.04	dB-Hz	101 Mb/s
Available Eb/No	11.91	dB	
Required Eb/No	10.50	dB	BER = 10^{-6}, uncoded
Coding Gain	0.00	dB	
Eb/No Margin	1.41	dB	

Ford Aerospace & Communications Corporation

SSA RETURN
USER TO BACKSIDE TO FRONTSIDE TO GROUND
12 MBPS; NO CODING; CARRIER FREQUENCY: 62.050 GHz

1.	USER EIRP, DBW	40.99	(Note 1)
2.	SPACE LOSS, DB	192.20	(Note 1)
3.	TDRSS G/T, DB/K	8.57	(Note 1)
4.	SIGNAL SUPPRESSION, DB	0.00	(Note 1)
5.	BOLTZMANNS CONST, DBW/HZ-K	-228.60	(Note 1)
6.	C/No AT BACKSIDE, DB-HZ	85.96	(Note 1)
7.	BANDWIDTH, DB-HZ	71.94	(Note 1)
8.	C/N AT BACKSIDE, DB-HZ	14.02	(Note 1)
9.	BACKSIDE-CROSSLINK EIRP, DBW	59.56	(Note 2)
10.	PATH LOSS, DB	-226.69	(83,043 KM)
11.	POLARIZATION LOSS, DB	.20	
12.	POINTING LOSS, DB	.33	
13.	TRACKING LOSS, DB	.33	
14.	FRONTSIDE-CROSSLINK REC. POWER DBI	-167.99	
15.	FRONTSIDE-CROSSLINK G/T, DB/K	34.24	(Note 3)
16.	BOLTZMANNS CONST, DBW/HZ-K	-228.60	
17.	P/No (THERMAL), DB-HZ	94.85	
18.	P/No (TOTAL) DB-HZ	94.85	
19.	BANDWIDTH, DB-HZ	71.94	
20.	P/N (TOTAL), DB	22.91	
21.	FRONTSIDE-DOWNLINK EIRP DBW	39.90	(Note 1)
22.	PATH LOSS, DB	207.70	(Note 1)
23.	ATMOSPHERIC LOSS, DB	1.10	(Note 1)
24.	POLARIZATION LOSS	.03	(Note 1)
25.	RAIN ATTENUATION, DB	6.00	(Note 1)
26.	GROUND RECEIVED POWER, DBI	-174.93	(Note 1)
27.	GROUND G/T, DB/K	41.70	(Note 1)
28.	BOLTZMANNS CONST, DBW/HZ-K	-228.60	(Note 1)
29.	P/No (THERMAL), DB-HZ	75.37	(Note 1)
30.	IM DEGRADATION, DB	1.22	(Note 1)
31.	P/No (TOTAL), DB-HZ	94.15	(Note 1)
32.	BANDWIDTH, DB-HZ	71.94	(Note 1)
33.	P/N (TOTAL), DB	22.21	(Note 1)
34.	C/N AT GROUND, DB	12.95	
35.	BANDWIDTH, DB-HZ	71.94	(Note 1)
36.	C/No AT GROUND, DB-HZ	84.89	
37.	DATA RATE, DB-BPS (300 MBPS)	70.79	(Note 1)
38.	Eb/No INTO DEMODULATOR, DB	14.10	
39.	GROUND EQUIPMENT DEC., DB	4.50	(Note 1)
40.	DIFF CODING LOSS, DB	.30	(Note 1)
41.	NET Eb/No, DB	9.30	
42.	THEORETICALLY REQUIRED Eb/No, DB	9.60	(Note 1)
43.	MARGIN WITH RAIN	-0.30	

Noise limits TDAS capability / Burden falls to user spacecraft

NOTES:

1) Values obtained from "TDRSS Telecommunications Performance and Interface Document (TPID)"

SE-09 12 March 1984 Table 1.1.1-3 page 1-9.

2) SSA Return Crosslink EIRP:

Transmitter Power, dBW	0.00
Combiner Loss, dB	-1.80
Transmission Line Loss, dB	-2.30
Feed Loss, dB	- .60
Transmit Antenna Gain, dBi	66.36
Antenna Efficiency, dB	-2.10
EIRP	59.56 dBW

3) SSA Return Crosslink G/T:

Receive Antenna Gain, dBi	66.36
Antenna Efficiency, dB	-2.10
Feed Loss, dB	-.60
Receive Line Loss, dB	-2.50
System Noise Temperature, dB-K	-26.92
G/T	34.24 dB/K

KSA RETURN
USER TO BACKSIDE TO FRONTSIDE TO GROUND
300 MBPS; NO CODING; CARRIER FREQUENCY: 62.775 GHz

1.	USER EIRP, DBW	57.37	(Note 1)
2.	SPACE LOSS, DB	209.20	(Note 1)
3.	TDRSS G/T, DB/K	23.94	(Note 1)
4.	BOLTZMANNS CONST, DBW/HZ-K	-228.60	(Note 1)
5.	C/No AT BACKSIDE, DB-HZ	100.71	(Note 1)
6.	BANDWIDTH, DB-HZ	83.73	(Note 1)
7.	C/N AT BACKSIDE, DB-HZ	16.98	(Note 1)
8.	BACKSIDE-CROSSLINK EIRP, DBW	67.46	(Note 2)
9.	PATH LOSS, DB	-226.78	(83,043 KM)
10.	POLARIZATION LOSS, DB	.20	
11.	POINTING LOSS, DB	.33	
12.	TRACKING LOSS, DB	.33	
13.	FRONTSIDE-CROSSLINK REC. POWER DBW	-160.18	
14.	FRONTSIDE-CROSSLINK G/T, DB/K	34.34	(Note 3)
15.	BOLTZMANNS CONST, DBW/HZ-K	-228.60	
16.	P/No (THERMAL), DB-HZ	102.76	
17.	P/No (TOTAL) DB-HZ	102.76	
18.	BANDWIDTH, DB-HZ	83.73	
19.	P/N (TOTAL), DB	19.03	
20.	FRONTSIDE-DOWNLINK EIRP DBW	52.90	(Note 1)
21.	PATH LOSS, DB	207.70	(Note 1)
22.	ATMOSPHERIC LOSS, DB	1.10	(Note 1)
23.	POLARIZATION LOSS	.03	(Note 1)
24.	RAIN ATTENUATION, DB	6.00	(Note 1)
25.	GROUND RECEIVED POWER, DBI	-161.93	(Note 1)
26.	GROUND G/T, DB/K	41.00	(Note 1)
27.	BOLTZMANNS CONST, DBW/HZ-K	-228.60	(Note 1)
28.	P/No (THERMAL), DB-HZ	107.67	(Note 1)
29.	CROSS POL. DEG., DB	.47	(Note 1)
30.	P/No (TOTAL), DB-HZ	107.20	(Note 1)
31.	BANDWIDTH, DB-HZ	83.73	(Note 1)
32.	P/N (TOTAL), DB	23.47	(Note 1)
33.	C/N AT GROUND, DB	14.31	
34.	BANDWIDTH, DB-HZ	83.73	(Note 1)
35.	C/No AT GROUND, DB-HZ	98.04	
36.	DATA RATE, DB-BPS (300 MBPS)	84.77	(Note 1)
37.	Eb/No INTO DEMODULATOR, DB	13.27	
38.	GROUND EQUIPMENT DEG., DB	4.05	(Note 1)
39.	DIFF CODING LOSS, DB	.30	(Note 1)
40.	NET Eb/No, DB	8.92	
41.	THEORETICALLY REQUIRED Eb/No, DB	9.60	(Note 1)
42.	MARGIN WITH RAIN	-0.68	

NOTES:

1) Values obtained from "TDRSS Telecommunications Performance and Interface Document (TPID)"

SE-09 12 March 1984 Table 1.1.1-4 page 1-11.

2) KSA Return Crosslink EIRP:

Transmitter Power, dBW	6.00
Transmission Line Loss, dB	-2.30
Feed Loss, dB	- .60
Transmit Antenna Gain, dBi	66.46
Antenna Efficiency, dB	-2.10
EIRP	67.46 dBW

3) KSA Return Crosslink G/T:

Receive Antenna Gain, dBi	66.46
Antenna Efficiency, dB	-2.10
Feed Loss, dB	-.60
Receive Line Loss, dB	-2.50
System Noise Temperature, dB-K	-26.92
G/T	34.34 dB/K

TT&C RETURN
BACKSIDE TO FRONTSIDE TO GROUND
10 Kbps: NO CODING: CARRIER FREQUENCY: 62.050 GHz

1.	BACKSIDE-CROSSLINK EIRP, DBW	49.86	(Note 2)	
2.	PATH LOSS, DB	-226.69	(83,043 KM)	
3.	POLARIZATION LOSS, DB	.20		
4.	POINTING LOSS, DB	.33		
5.	TRACKING LOSS, DB	.33		
6.	FRONTSIDE-CROSSLINK REC. POWER DBI	-166.83		
7.	FRONTSIDE-CROSSLINK G/T, DB/K	34.24	(Note 3)	
8.	BOLTZMANNS CONST, DBW/HZ-K	-228.60		
9.	C/No (THERMAL), DB-HZ	96.01		
10.	C/No (TOTAL) DB-HZ	96.01		
11.	BANDWIDTH, DB-HZ	64.77	(Note 1)	
12.	C/N (TOTAL), DB	21.24		
13.	FRONTSIDE-DOWNLINK EIRP DBW	28.52	(Note 1)	
14.	PATH LOSS, DB	207.43	(Note 1)	
15.	ATMOSPHERIC LOSS, DB	1.30	(Note 1)	
16.	POLARIZATION LOSS	0.00	(Note 1)	
17.	RAIN ATTENUATION, DB	15.00	(Note 1)	
18.	GROUND RECEIVED POWER, DBI	-195.21	(Note 1)	
19.	GROUND G/T, DB/K	41.40	(Note 1)	
20.	BOLTZMANNS CONST, DBW/HZ-K	-228.60	(Note 1)	
21.	DEG. DUE TO TRANSMIT S/N	.98	(Note 1)	(BW=64.77 dB-HZ) (S/N = 16 dB)
22.	P/No (THERMAL), DB-HZ	73.81	(Note 1)	
23.	TELEMETRY MOD. LOSS, DB	4.58	(Note 1)	
24.	BANDWIDTH, DB-HZ	64.77	(Note 1)	
25.	P/N (TOTAL), DB	4.46	(Note 1)	
26.	C/N AT GROUND, DB	4.37		
27.	BANDWIDTH, DB-HZ	64.77	(Note 1)	
28.	C/No AT GROUND, DB-HZ	69.14		
29.	DATA RATE, DB-BPS (10 KBPS)	40.00	(Note 1)	
30.	RECEIVER LOSS, DB	2.20	(Note 1)	
31.	DEMODULATOR LOSS, DB	1.80	(Note 1)	
32.	RECEIVED SNR, DB	35.14		
33.	REQUIRED SNR, DB	11.00	(Note 1)	
34.	TELEMETRY MARGIN	14.14		

NOTES:

1) Values obtained from "TDRSS Telecommunications Performance and Interface Document (TPID)"

SE-09 12 March 1984 Table 1.3.1-4 page 1-68.

2) TT&C Return Crosslink EIRP:

Transmitter Power, dBW	-10.00
Combiner Loss, dB	-1.50
Transmission Line Loss, dB	-2.30
Feed Loss, dB	- .60
Transmit Antenna Gain, dBi	66.36
Antenna Efficiency, dB	-2.10
EIRP	49.86 dBW

3) TT&C Return Crosslink G/T:

Receive Antenna Gain, dBi	66.36
Antenna Efficiency, dB	-2.10
Feed Loss, dB	-.60
Receive Line Loss, dB	-2.50
System Noise Temperature, dB-K	-26.92
G/T	34.24 dB/K

Ford Aerospace & Communications Corporation

Forward Channel without Sun Effect; Baseband Signals

Modulation: QPSK
Coding: None

Carrier Frequency = 54.3 GHz

Parameter	Value	Units	Remarks
Transmitting S/C Power	0.00	dBW	1.0 watts
Transmit Line Loss	3.80	dB	
Feed Loss	0.60	dB	
Transmitting Antenna Gain	63.10	dBi	3.2-m dish
EIRP	58.70	dBW	
Free Space Loss	225.53	dB	83,043 km
Pointing Loss	0.33	dB	0.02 degree
Polarization Loss	0.20	dB	
Tracking Loss	0.33	dB	0.02 degree
Net Path Loss	226.39	dB	
Receiving S/C Antenna Gain	63.10	dBi	3.2-m dish; Temp. = 10 K
Feed Loss	0.60	dB	Temp.= 10 K
Receive Line Loss	2.50	dB	Temp.= 290 K
Receiver Temperature			360 K
System Noise Temperature	26.92	dB-K	492.5 K at Receiver Input
Effective G/T	33.08	dB/K	
Received Carrier Level	-107.69	dBW	At Receiver Input
Boltzmann's Constant	-228.60	dBW/Hz-K	
Received C/No	93.98	dB-Hz	
CCI Degradation	0.00	dB	
ISI Degradation	1.07	dB	
Modem Loss	2.00	dB	
Data Rate	77.48	dB-Hz	56 Mb/s
Available Eb/No	13.43	dB	
Required Eb/No	10.50	dB	BER = 10^{-6}, uncoded
Coding Gain	0.00	dB	
Eb/No Margin	2.93	dB	

Forward Channel without Sun Effect; Baseband Signals

Modulation: SQPSK
Coding: None

Carrier Frequency = 54.3 GHz

Parameter	Value	Units	Remarks
Transmitting S/C Power	0.00	dBW	1.0 watts
Transmit Line Loss	3.80	dB	
Feed Loss	0.60	dB	
Transmitting Antenna Gain	63.10	dBi	3.2-m dish
EIRP	58.70	dBW	
Free Space Loss	225.53	dB	83,043 km
Pointing Loss	0.33	dB	0.02 degree
Polarization Loss	0.20	dB	
Tracking Loss	0.33	dB	0.02 degree
Net Path Loss	226.39	dB	
Receiving S/C Antenna Gain	63.10	dBi	3.2-m dish; Temp. = 10 K
Feed Loss	0.60	dB	Temp.= 10 K
Receive Line Loss	2.50	dB	Temp.= 290 K
Receiver Temperature			360 K
System Noise Temperature	26.92	dB-K	492.5 K at Receiver Input
Effective G/T	33.08	dB/K	
Received Carrier Level	-107.69	dBW	At Receiver Input
Boltzmann's Constant	-228.60	dBW/Hz-K	
Received C/No	93.98	dB-Hz	
CCI Degradation	0.00	dB	
ISI Degradation	1.07	dB	
Modem Loss	2.00	dB	
Data Rate	77.48	dB-Hz	56 Mb/s
Available Eb/No	13.43	dB	
Required Eb/No	10.50	dB	BER = 10^{-6}, uncoded
Coding Gain	0.00	dB	
Eb/No Margin	2.93	dB	

SSA FORWARD
FRONTSIDE TO BACKSIDE
0.3 MBPS; NO CODING; CARRIER FREQUENCY = 54.300 GHz

1.	FRONTSIDE CROSSLINK EIRP, DBW	42.71	(Note 1)
2.	PATH LOSS, DB	-225.52	(83,043 KM)
3.	POLARIZATION LOSS, DB	.20	
4.	POINTING LOSS, DB	.33	
5.	TRACKING LOSS, DB	.33	
6.	BACKSIDE CROSSLINK REC., POWER DBI	-183.67	
7.	BACKSIDE CROSSLINK G/T, DB/K	33.09	(Note 2)
8.	BOLTZMANNS CONST., DBW/HZ-K	-228.60	
9.	P/No (THERMAL), DB-HZ	78.02	
10.	P/No (TOTAL), DB-HZ	78.02	
11.	BANDWIDTH, DB-HZ	55.16	(328 KHz)
12.	P/N (TOTAL), DB	22.86	

NOTES:

1) SSA Forward Crosslink EIRP:

Transmitter Power, dBW	-16.00	(25 mW)
Combiner Loss, dB	-1.50	
Transmission Line Loss, dB	-2.30	
Feed Loss, dB	- .60	
Transmit Antenna Gain, dBi	65.21	
Antenna Efficiency, dB	-2.10	
EIRP	42.71 dBW	

2) SSA Forward Crosslink G/T:

Receive Antenna Gain, dBi	65.21
Antenna Efficiency, dB	-2.10
Feed Loss, dB	-.60
Receive Line Loss, dB	-2.50
System Noise Temperature, dB-K	-26.92
G/T	33.09 dB/K

KSA FORWARD
FRONTSIDE TO BACKSIDE
25 MBPS; NO CODING; CARRIER FREQUENCY = 54.300 GHz

1.	FRONTSIDE CROSSLINK EIRP, DBW	62.01	(Note 1)
2.	PATH LOSS, DB	-225.52	(83,043 KM)
3.	POLARIZATION LOSS, DB	.20	
4.	POINTING LOSS, DB	.33	
5.	TRACKING LOSS, DB	.33	
6.	BACKSIDE CROSSLINK REC., POWER DBI	-164.37	
7.	BACKSIDE CROSSLINK G/T, DB/K	33.09	(Note 2)
8.	BOLTZMANNS CONST., DBW/HZ-K	-228.60	
9.	P/No (THERMAL), DB-HZ	97.32	
10.	P/No (TOTAL), DB-HZ	97.32	
11.	BANDWIDTH, DB-HZ	73.98	(27.3 MHz)
12.	P/N (TOTAL), DB	23.34	

NOTES:

1) KSA Forward Crosslink EIRP:

Transmitter Power, dBW	3.00	(2 W)
Combiner Loss, dB	-1.20	
Transmission Line Loss, dB	-2.30	
Feed Loss, dB	- .60	
Transmit Antenna Gain, dBi	65.21	
Antenna Efficiency, dB	-2.10	
EIRP	62.01	dBW

2) KSA Forward Crosslink G/T:

Receive Antenna Gain, dBi	65.21	
Antenna Efficiency, dB	-2.10	
Feed Loss, dB	-.60	
Receive Line Loss, dB	-2.50	
System Noise Temperature, dB-K	-26.92	
G/T	33.09	dB/K

TT&C FORWARD
FRONTSIDE TO BACKSIDE
0.01 MBPS; NO CODING; CARRIER FREQUENCY = 54.300 GHz

1.	FRONTSIDE CROSSLINK EIRP, DBW	49.01	(Note 1)
2.	PATH LOSS, DB	-225.52	(83,043 KM)
3.	POLARIZATION LOSS, DB	.20	
4.	POINTING LOSS, DB	.33	
5.	TRACKING LOSS, DB	.33	
6.	BACKSIDE CROSSLINK REC., POWER DBI	-177.37	
7.	BACKSIDE CROSSLINK G/T, DB/K	33.09	(Note 2)
8.	BOLTZMANNS CONST., DBW/HZ-K	-228.60	
9.	P/No (THERMAL), DB-HZ	84.32	
10.	P/No (TOTAL), DB-HZ	84.32	
11.	BANDWIDTH, DB-HZ	40.41	(11 KHz)
12.	P/N (TOTAL), DB	43.91	

NOTES:

1) TT&C Forward Crosslink EIRP:

Transmitter Power, dBW	-10.00	(100 mW)
Combiner Loss, dB	-1.20	
Transmission Line Loss, dB	-2.30	
Feed Loss, dB	- .60	
Transmit Antenna Gain, dBi	65.21	
Antenna Efficiency, dB	-2.10	
EIRP	49.01 dBW	

2) TT&C Forward Crosslink G/T:

Receive Antenna Gain, dBi	65.21
Antenna Efficiency, dB	-2.10
Feed Loss, dB	-.60
Receive Line Loss, dB	-2.50
System Noise Temperature, dB-K	-26.92
G/T	33.09 dB/K

CHANNELIZED 60 GHz CROSSLINK

LINK RELIABILITY
P_S(10 years)

Link Name	Single Thread W/O Drive	Single Thread W Drive*	With Redundancy W/O Drive	With Redundancy W Drive*
LSA Return	0.1430	0.1339	0.8962	0.8392
LSA Forward	0.7071	0.6622	0.9589	0.8980
WSA Return	0.6039	0.5655	0.9340	0.8746
WSA Forward	0.7071	0.6622	0.9589	0.8980
TT&C Return	0.7342	0.6875	0.9669	0.9054
TT&C Forward	0.7304	0.6840	0.9655	0.9041
SMA Return	0.6362	0.5958	0.9437	0.8837
SMA Forward	0.7071	0.6622	0.9589	0.8980
KSA Return	0.5979	0.5599	0.9228	0.8641
KSA Forward	0.6679	0.6255	0.9481	0.8878
SSA Return	0.7111	0.6659	0.9607	0.8996
SSA Forward	0.7294	0.6830	0.9642	0.9029

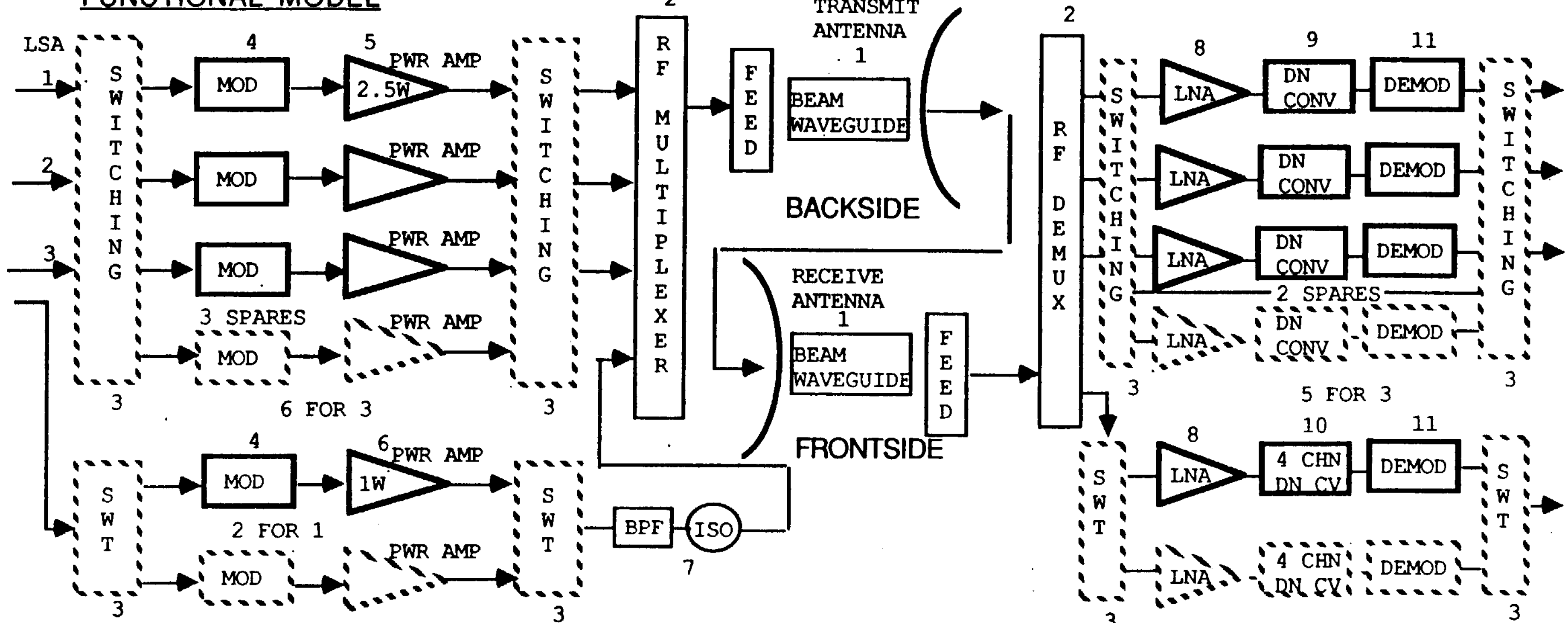
* Antenna drive mechanisms include redundant electronics

Reliability Modeling Assumptions

The following reliability assumptions are incorporated in the link reliability models:

- High reliability parts and components in accordance with typical long life spacecraft.
- Part derating policies in accordance with MIL-STD-1547 and PPL-17 for a 10 year mission.
- 12 year design life for electronics and antenna drive mechanisms.
- Operating temperatures for assemblies typical of 3 axis spacecraft in geosynchronous orbit.
- Failure rates for piece parts in accordance with MIL-HDBK-217D, Notice 1.

FUNCTIONAL MODEL



RELIABILITY MODEL

		F.R.
1.	ANTENNA/BEAM WG/ FEED	28.5
2.	MULTIPLEXER PORT	10
3.	SWITCH PORT	5
4.	MODULATOR	1545
5.	2.5W PWR AMP	1515
6.	1W PWR AMP	865
7.	BPF/ISOLATOR	10
8.	LNA	150
9.	DOWN CONVERTER (1 CHN)	1355
10.	DOWN CONVERTER (4 CHN)	1400
11.	DEMODULATOR	1095

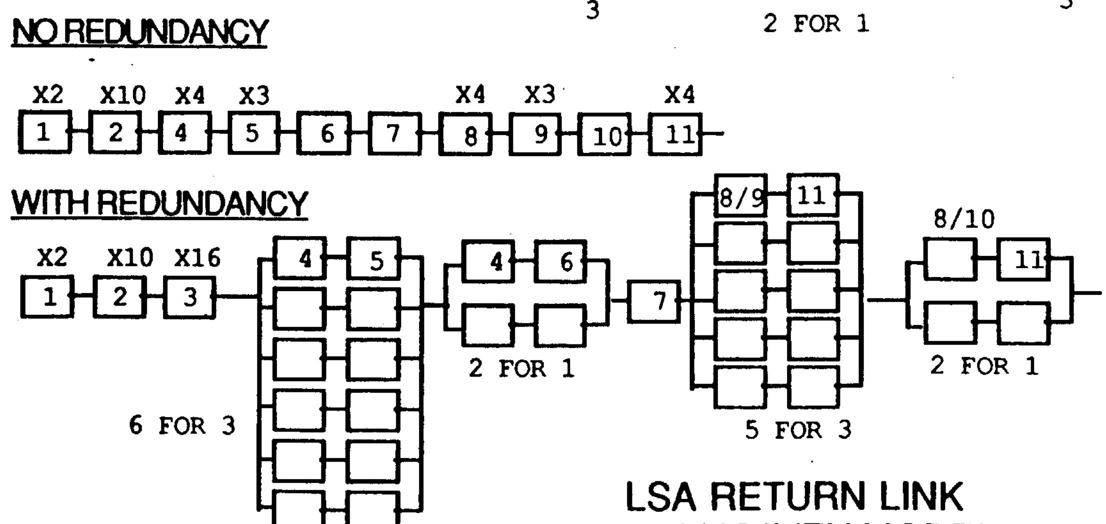


FIGURE 1

LSA RETURN LINK RELIABILITY MODEL

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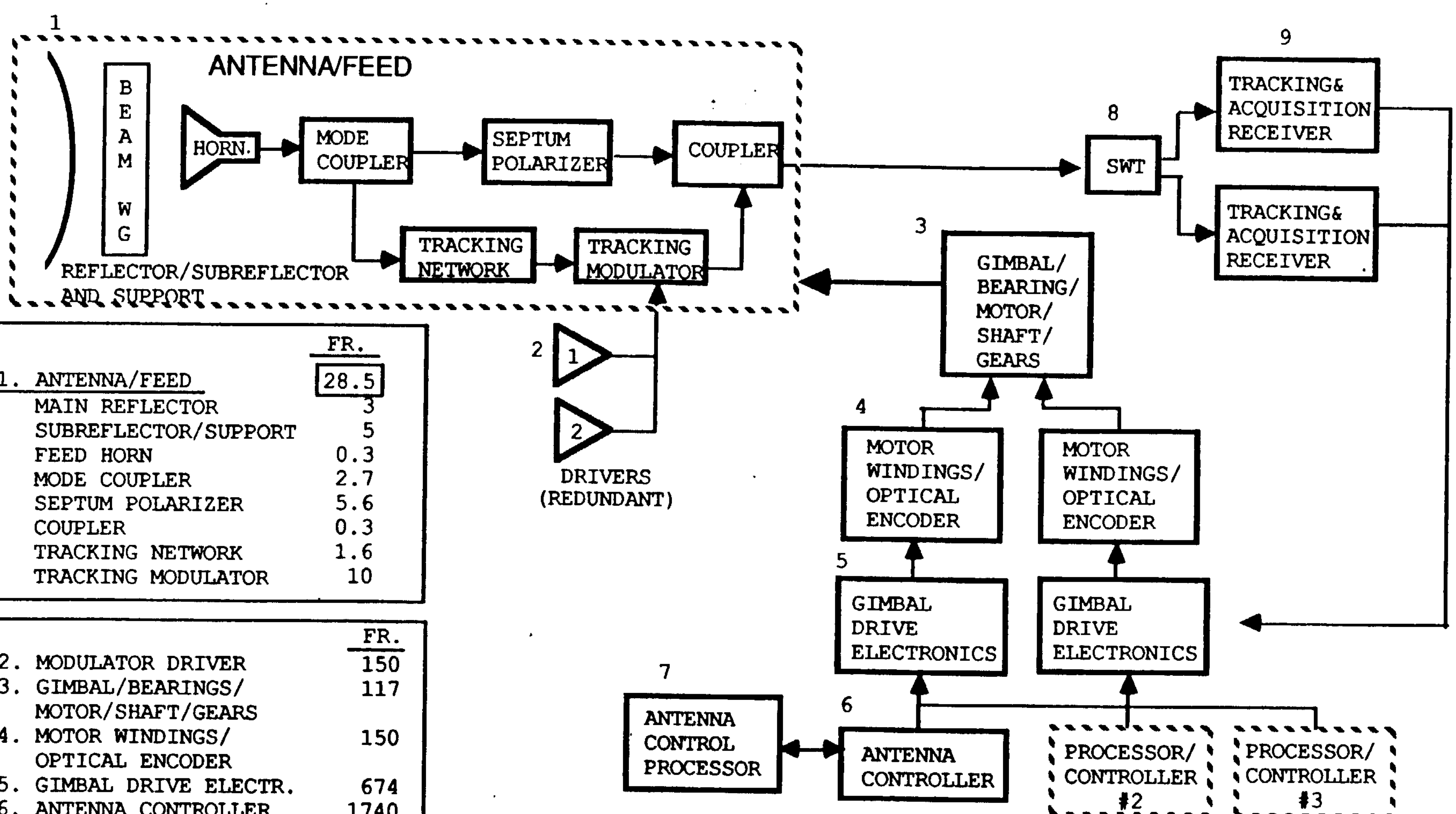
FUNCTIONAL MODEL

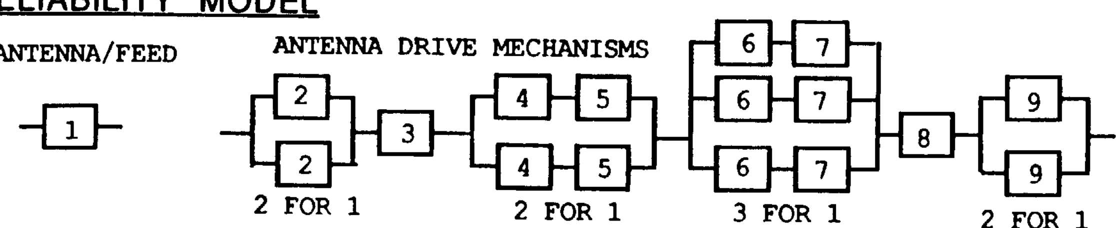


	FR.
1. ANTENNA/FEED	$\boxed{28.5}$
MAIN REFLECTOR	3
SUBREFLECTOR/SUPPORT	5
FEED HORN	0.3
MODE COUPLER	2.7
SEPTUM POLARIZER	5.6
COUPLER	0.3
TRACKING NETWORK	1.6
TRACKING MODULATOR	10

	FR.
2. MODULATOR DRIVER	150
3. GIMBAL/BEARINGS/ MOTOR/SHAFT/GEARS	117
4. MOTOR WINDINGS/ OPTICAL ENCODER	150
5. GIMBAL DRIVE ELECTR.	674
6. ANTENNA CONTROLLER	1740
7. ANTENNA CONTROL PROC.	2340
8. SWITCH PORT	10
9. TRACKING ACQ. RECEIVER	1721

NOTE; ANTENNA/FEED ITEMS ARE INCLUDED IN THE RETURN AND FORWARD LINK RELIABILITY MODELS.

RELIABILITY MODEL



ANTENNA & DRIVE MECHANISMS RELIABILITY MODEL

FIGURE 11

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60 GHz CHANNELIZED CROSSLINK (GEO-GEO)
POWER, WEIGHT AND SIZE

FRONTSIDE SATELLITE

EQUIPMENT	QNTY	WT. LBS (EA)	POWER W	SIZE In x In x In	REDUN-DANCY	TOTAL WT	TOTAL POWER
RETURN LINKS							
Low Noise Amplifier	11	4.3	28	1x3x.75	10	90.3	308
Down Converter	10	5	24	5x4x2	9	95.0	240
Demodulator	9	3	6	3x4x2	8	51.0	54
Four Ch. Down Convert	1	13	30	6x4x2	1	26.0	30
Rf Demultiplexer	1	1.5	-	8x1x1	-	1.5	-
FORWARD LINKS							
60 GHz Modulator & Source	1	5	24	5x4x2	1	10.0	24
Power Amp (1W)	1	0.5	11	4x2x1	1	1.0	11
Power Amp (0.025W)	2	0.3	0.3	3.3x2x1	2	1.2	0.6
Power Amp (2W)	2	0.7	22	10x5x1.5	2	2.8	44
Power Amp (0.1W)	1	0.3	1	3.3x2x1	1	0.6	1
Up Converter	5	5	24	5x4x2	5	50.0	120
Power Combiner	1	0.7	-	8x1x1	-	0.7	-
Bandpass Filter	1	0.1	-	2x1x1	-	0.1	-
COMMON							
Feed Assembly	1	3.5	-	4x4x18	-	3.5	-
Antenna (3.2m)	1	60.5	-	126x126x35	-	60.5	-
Gimbal Subsystem	1	28	9	14x13x5x11	-	28.0	9
Gimbal Drive Elec	1	5	6	8.5x2.6x5.7	1	10.0	6
Acquisition & Track Rcvr	1	1.2	4	3x6x2	1	2.4	4
Antenna Controller	6	0.5	0.1	4x8x.5	12	9.0	0.6
Ant. Cntrl. Microproc.	1	0.5	0.4	4x8x.5	2	1.5	0.4
DC/DC Converter	1	4	213.2		2	12.0	213.2

TOTAL WEIGHT: 278.1 lbs (single string)
457.1 lbs (with redundancy)

TOTAL POWER: 1,065.8 watts

60 GHz CHANNELIZED CROSSLINK (GEO-GEO) POWER, WEIGHT AND SIZE

BACKSIDE SATELLITE

EQUIPMENT	QNTY	WT. LBS (EA)	POWER W	SIZE In x In x In	REDUN-DANCY	TOTAL WT	TOTAL POWER
RETURN LINKS							
60 GHz Modulator & Source	9	5	24	5x4x2	9	90.0	216
Power Amp (2.5W)	8	0.7	27	10x5x1.5	8	11.2	216
Power Amp (1W)	3	0.5	11	4x2x1	3	3.0	33
Power Amp (4W)	2	0.9	43	10x5x1.5	2	3.6	86
Power Amp (0.1W)	1	0.3	1	3.3x2x1	1	0.6	1
Up Converter	5	5.0	24	5x4x2	5	50.0	120
Power Combiner	1	0.5	-	6x1x1	-	0.5	-
RF Multiplexer	1	1.5	-	8x1x1	-	1.5	-
FORWARD LINKS							
Bandpass Filter	1	0.1	-	2x1x1	-	0.1	-
Low Noise Amp	1	4.3	28	1x3x3/4	1	8.6	28
Six Ch Down Convert	1	15	30	8x4x2	1	30.0	30
IF Demodulator	1	3	6	3x4x2	1	6.0	6
COMMON							
Feed Assembly	1	3.5	-	4x4x18	-	3.5	-
Antenna (3.2m)	1	60.5	-	126x126x35	-	60.5	-
Gimbal Subsystem	1	28	9	14x13.5x11	-	28.0	9
Gimbal Drive Elec	1	5	6	8.5x2.6x5.7	1	10.0	6
Acquisition & Track Rcvr	1	1.2	4	3x6x2	1	2.4	4
Antenna Controller	6	0.5	0.1	4x8x.5	12	9.0	0.6
Ant. Cntrl. Microproc.	1	0.5	0.4	4x8x.5	2	1.5	0.4
DC/DC Converter	1	4.0	189		2	12.0	189

TOTAL WEIGHT: 209.3 lbs (single string)
354.6 lbs (with redundancy)

TOTAL POWER: 945 watts

ANTENNAS

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SELECTION OF ANTENNA TYPE

Candidates

- Electronically scanned array or MBA
- Mechanically scanned
- Hybrid electronic/mechanical scan
- Gimballed dual reflector with fixed feed

SELECTION OF ANTENNA TYPE

Discriminators

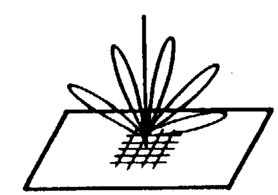
- Requirements
  - High gain
  - Coverage
- Performance
  - Mass and volume
  - Reliability
  - Impact on host spacecraft
- Developmental
  - Technical risk
  - Cost

ELECTRONICALLY SCANNED ANTENNA

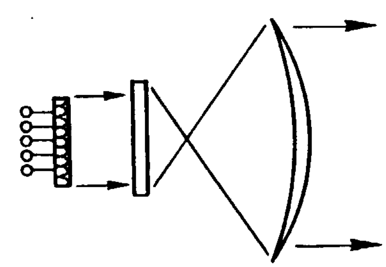
- Description
  - Multiple beams from one aperture
  - Spatial power combining
  - Complex beamforming network to form multiple beams
- Advantages
  - No torque (mechanical) noise
  - Negligible scan time
- Disadvantages
  - Limited scan range
    - 100 beamwidths maximum
    - Limited in angle
  - Increased weight and volume
  - Excessive technical risk

CONFIGURATION

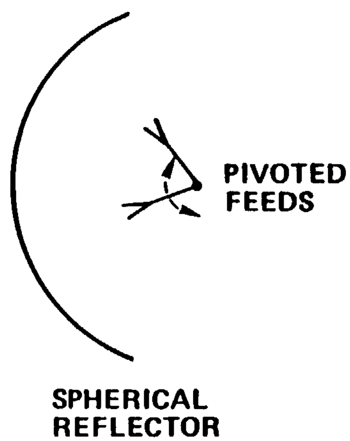
DIRECT PHASED ARRAY



PHASED ARRAY FEEDING A CONJUGATE IMAGING LENS

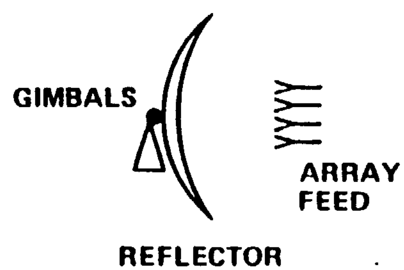


MECHANICALLY SCANNED ANTENNA



- Description
  - Oversize spherical main reflector to achieve wide angle coverage via feed motion only
- Advantages
  - Reliable
- Disadvantages
  - Problem with feed pivot RF connection: solved by use of beam waveguide
  - Difficult to follow multiple objects with multiple feeds

HYBRID ELECTRONIC/MECHANICAL SCAN ANTENNA



- o Description
  - Array feed for limited electronic scanning
  - Gimbals for full mechanical scanning
- o Advantages
  - Useful for search and acquisition
- o Disadvantages
  - Limited scan capability about boresight
  - Complexity outweighs potential benefits

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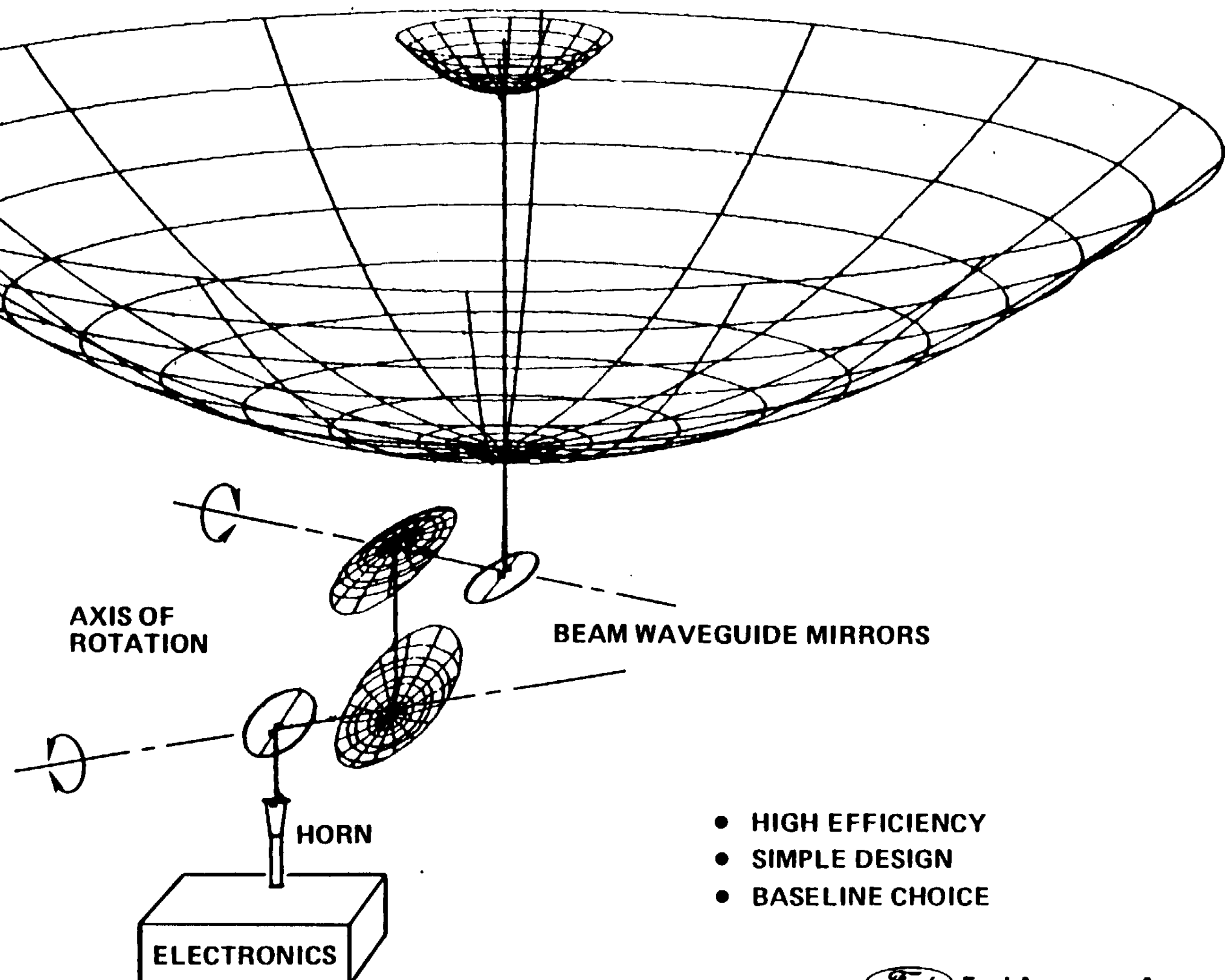
GIMBALLED DUAL REFLECTOR, FIXED FEED



- HIGH EFFICIENCY
- SIMPLE DESIGN
- BASELINE CHOICE

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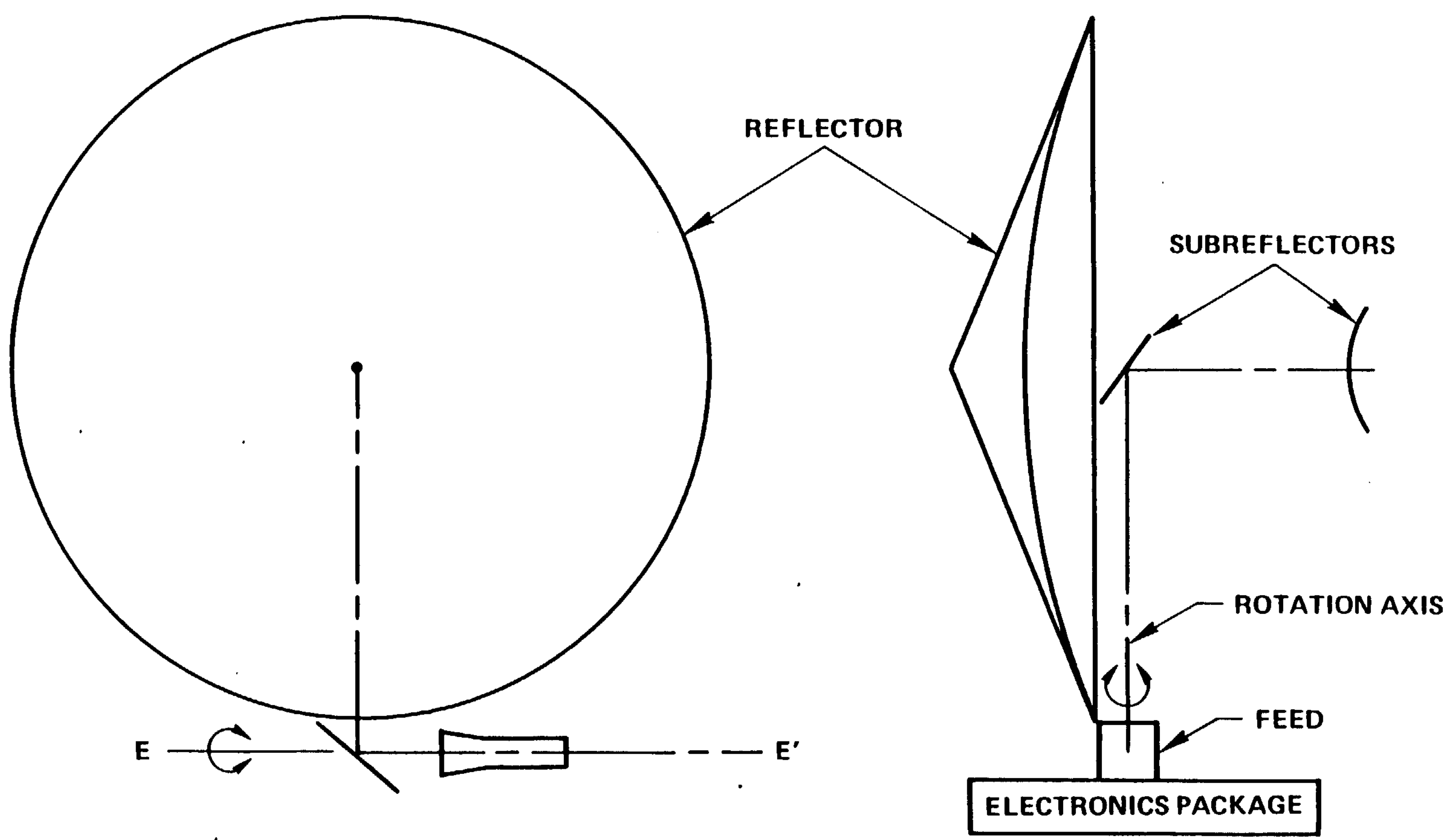
GIMBALLED DUAL REFLECTOR, FIXED FEED
(ALTERNATE DESIGN)



- SINGLE ROTATION AXIS
- DIRECT RADIATION TRANSMISSION OF RF POWER

BASELINE GEO CROSSLINK ANTENNA

- Description
  - Axially fed Cassegrain with dual shaped reflectors
  - Mechanically steered around two axes
  - Full duplex link, separated by polarization and frequency

- Performance
  - Ideal gain at 60 GHz: 66.1 dB
  - Antenna efficiency: -2.1 dB
  - Net gain: 64.0 dB

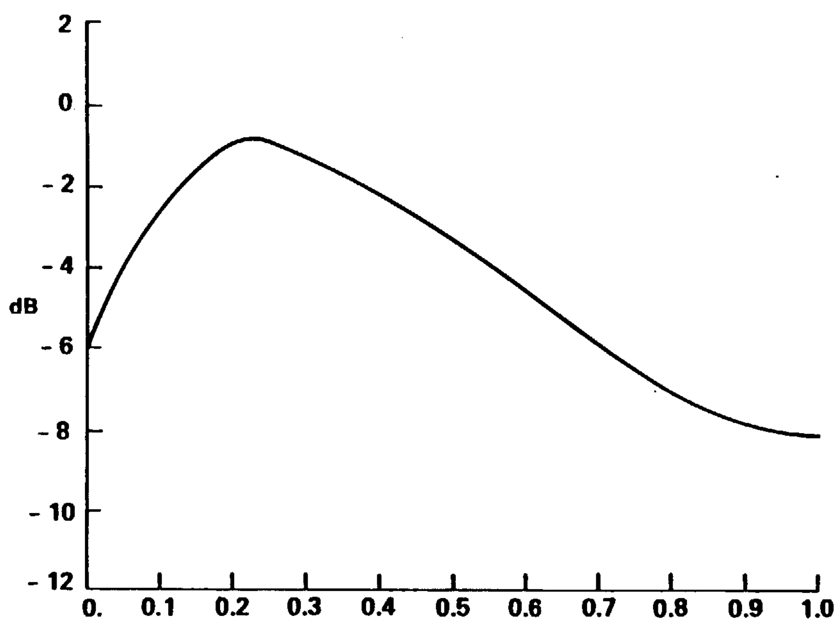
BASELINE GEO CROSSLINK ANTENNA (Continued)

- Feed Design
  - Circular polarization radiated via Septum polarizer
  - Focal lengths chosen such that feed is near apex
  - Beam waveguide transmits RF signals through gimbals
  - Monopulse tracking via TE_{21} modes for error pattern and TE_{11} for main beam

- Mechanical Design
  - Diameter: 3.2 m
  - Composite materials used for maximum strength, minimum weight, and thermal stability
  - Mass of antenna, subreflector, and feed assemblies: 27 kg

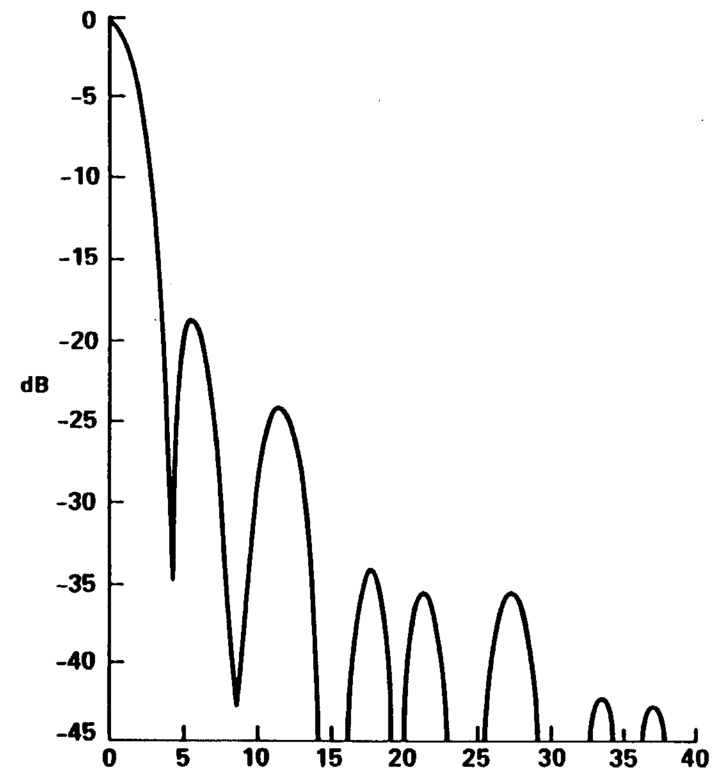
ANTENNA DESIGN

DUAL REFLECTOR
AXIALLY FED, FEED NEAR VERTEX
SHAPED SURFACES
HIGH EFFICIENCY
LOW FIRST SIDELOBE LEVEL



APERTURE DISTRIBUTION

TAYLOR DISTRIBUTION, P = O, 25 dB
WITH 6 dB ROLLOFF AT CENTER



RADIATION PATTERN

APERTURE EFFICIENCY: 0.89
FIRST SIDELOBES: - 18.6 dB

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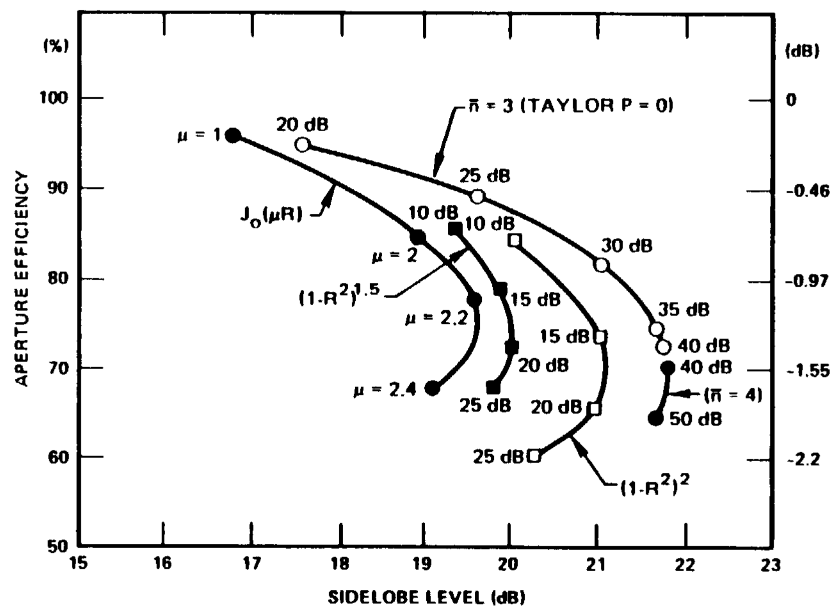
APERTURE EFFICIENCY VERSUS SIDELOBE LEVEL



- Results for 20% center blockage (4% area)
- Three types of aperture distribution
  - — $(1 - R^2)^N$
  - — Bessel function, J_o (μR)
  - — Taylor distribution
- Taylor distributions have best combination of low sidelobes and high efficiency

BEAM WAVEGUIDE

- Problem
  - To transmit RF power between steerable antenna and fixed electronics module
- Discriminators
  - Length of transmission path
  - Number of rotation axes
  - Amount of rotation about axes

BEAM WAVEGUIDE OPTIONS

- WR-15 rectangular waveguide
  - Excessive loss (1.5 dB/m)
- Coaxial line
  - Excessive loss
- Oversize rectangular of circular waveguide
  - Low loss
  - Must be straight
- Circular TE_{01} waveguide
  - Low loss in larger sizes
  - Must be straight
  - Higher launching losses
  - Propagates other modes

BEAM WAVEGUIDE OPTIONS (Continued)

- Flexible dielectric waveguide
  - Low loss (0.1 dB/m)
  - Launching loss (0.4 dB)
  - Unknown space qualification
  - $\pm 90^\circ$ motion
  - 10° phase change with motion
- Direction radiation from horn to subreflector
  - Only possible with 1-axis systems
- Beam waveguide
  - System of mirrors
  - Small launching loss (0.3 dB)
  - Low loss over long distances

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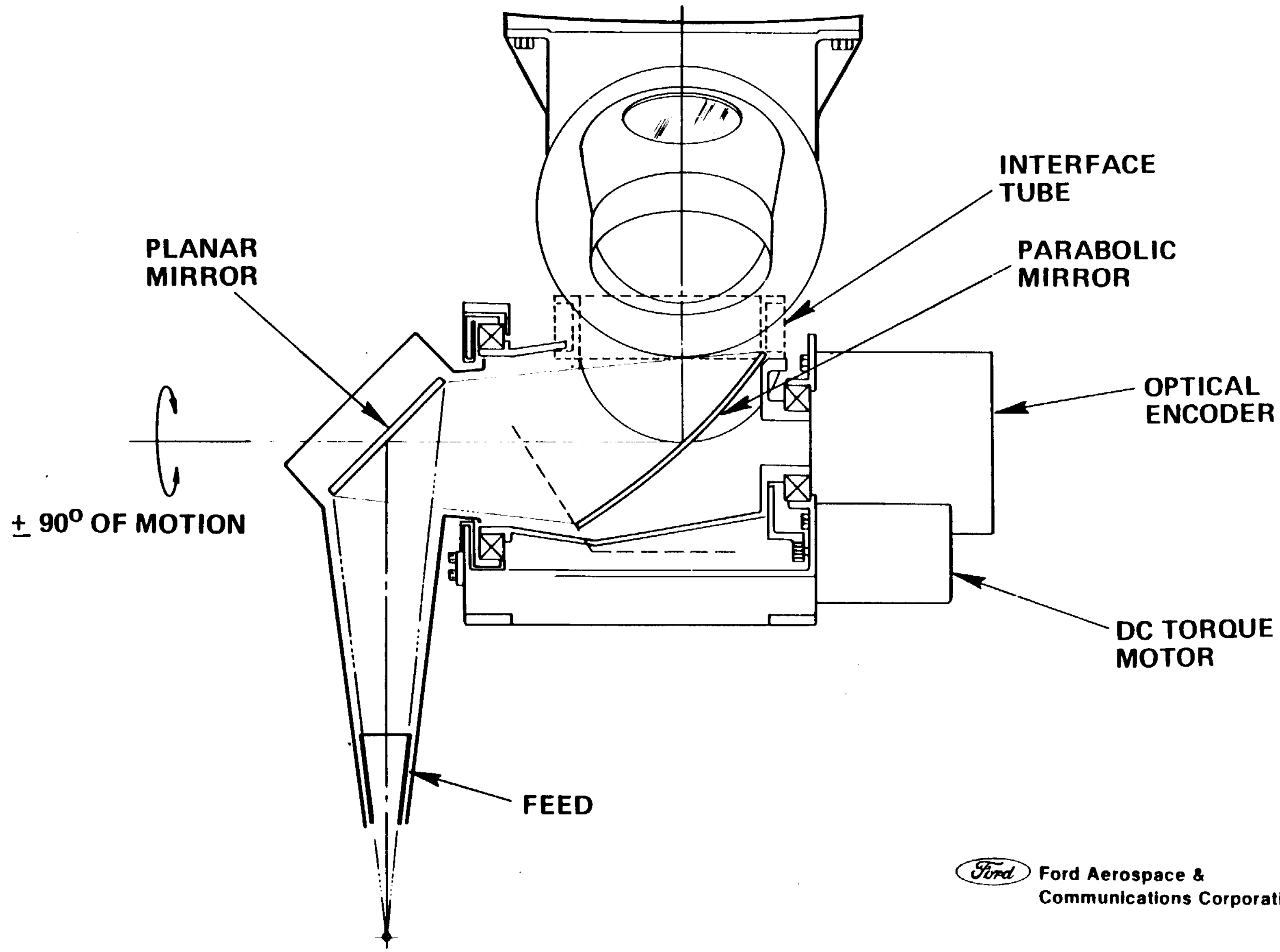
BASELINE APPROACH
BEAM WAVEGUIDE DETAIL



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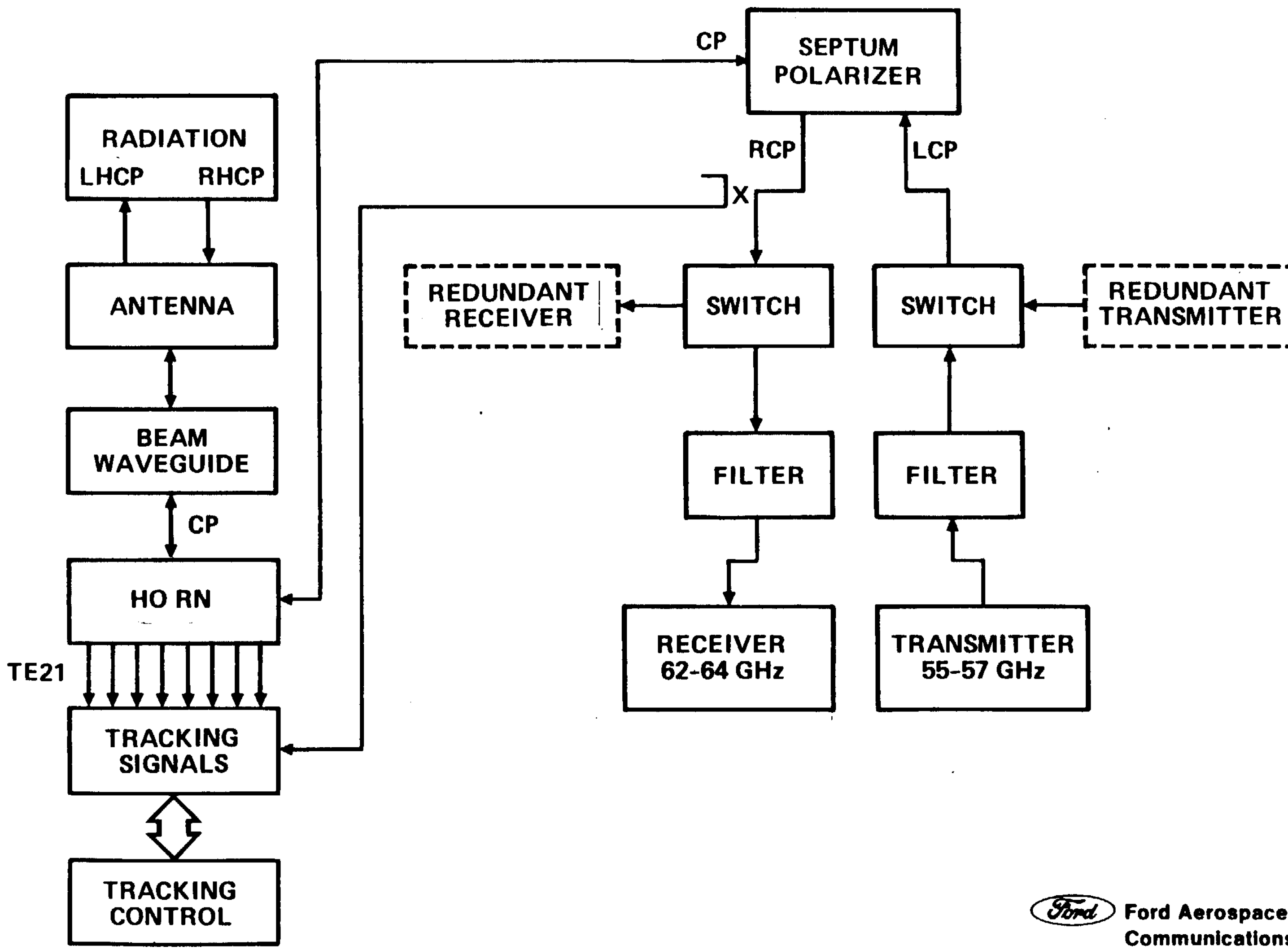
ANTENNA SYSTEM SCHEMATIC



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RECEIVER

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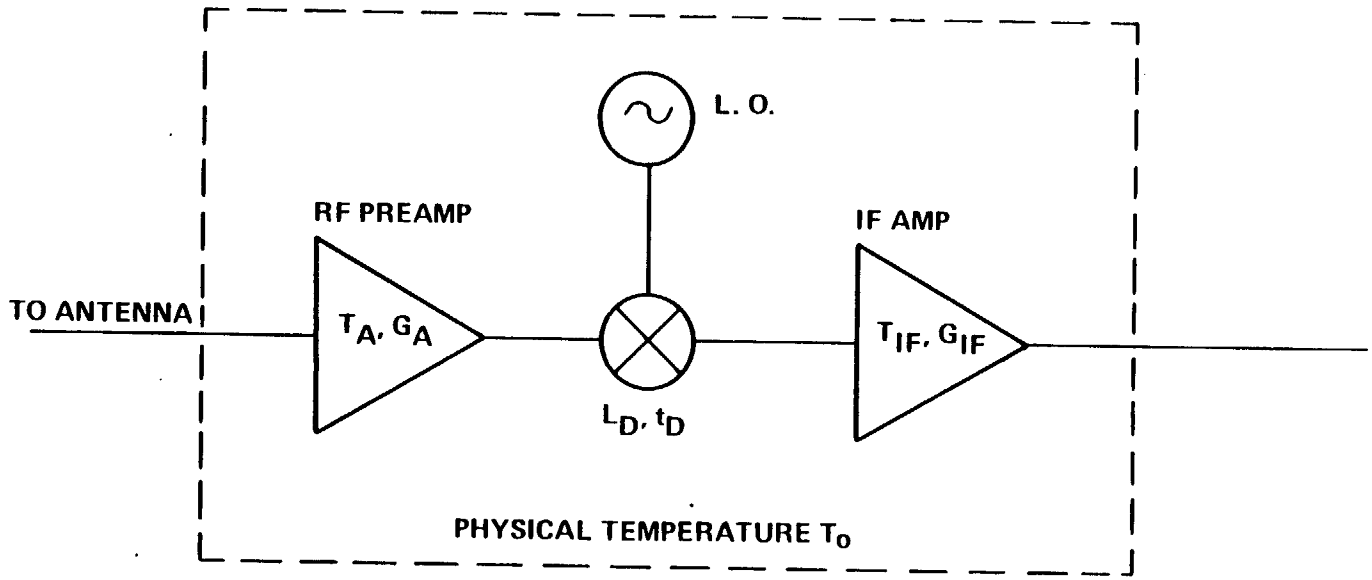
RECEIVER FRONT END



$$T_e = T_A + \frac{(L_D T_D - 1)\, T_o + L_D T_{IF}}{G_A}$$

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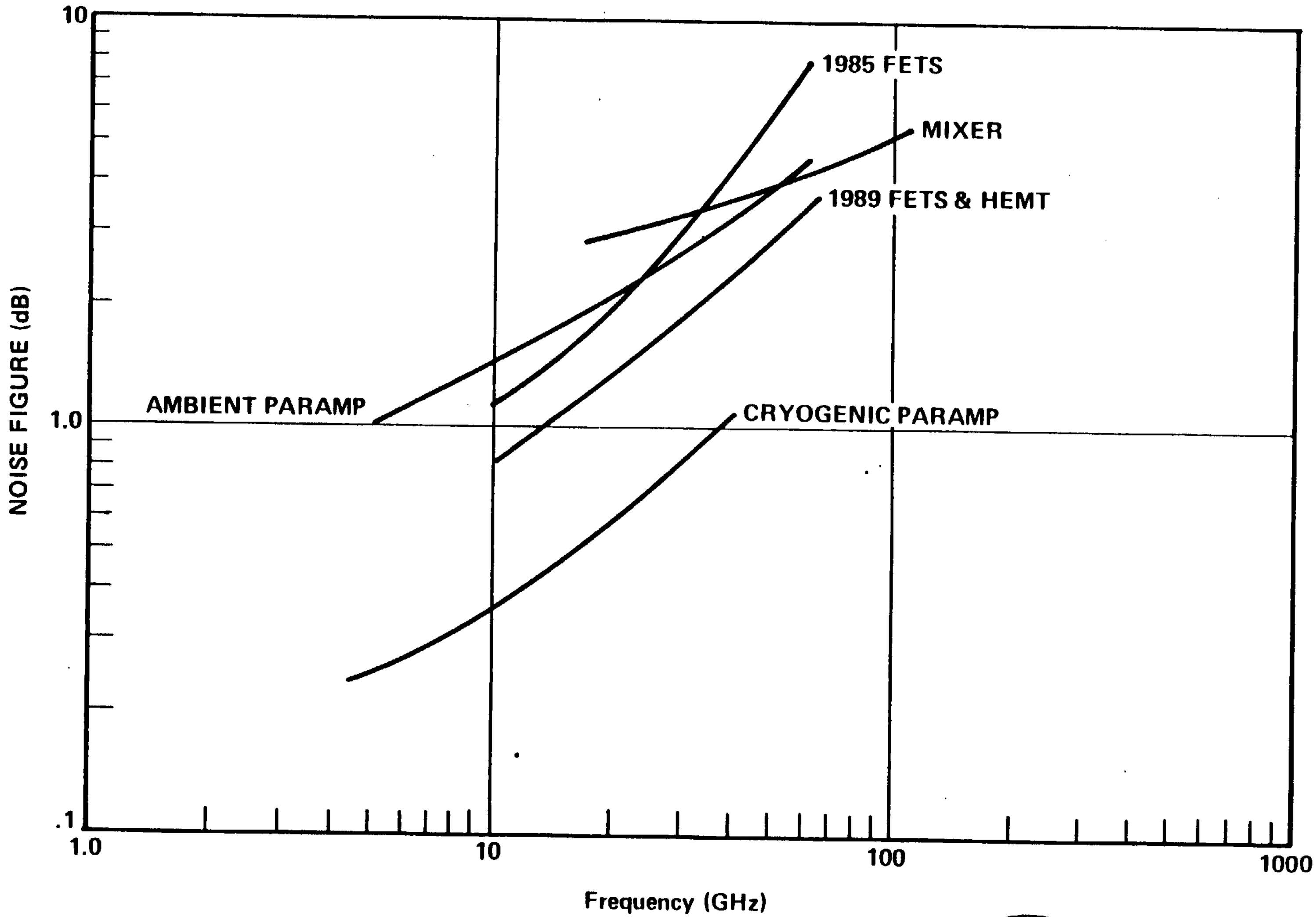

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60 GHz LOW NOISE AMPLIFIERS

- Parametric Amplifiers
  - Low noise
  - Complex, poor reliability
  - Large and heavy
  - Require $>$100 GHz pump for low noise at 60 GHz
- Gunn amplifiers (GaAs or InP)
  - 15 dB noise figure makes them unsuitable

60 GHz LOW NOISE AMPLIFIERS
(Continued)

- FETs
  - Very low noise at lower frequencies
  - As low as 2 dB at 30 GHz, 3.5 dB at 44 GHz reported
  - 7 to 9 dB noise figure to date at 60 GHz
  - Probability of significant improvement at 60 GHz

- High Electron Mobility Transistor (HEMT)
  - New device promises low noise at 60 GHz
  - Has achieved 2.7 dB noise figure at 34 GHz
  - As low as 2.3 dB at 60 dB has been predicted

CANDIDATES FOR LOCAL OSCILLATOR

- Gunn oscillators (GaAs or InP)
  - Well established as RF source at 60 GHz
  - Low noise
  - Simple bias requirements
  - Low power, but adequate for LO
- Impatt oscillators
  - Higher power than Gunns
  - Noise worse than Gunns

CANDIDATES FOR LOCAL OSCILLATOR
(Continued)

- FET
  - May not have enough power output for LO by 1989
  - Noise as oscillator no better than Gunn, possibly worse
  - Possibly more efficient than Gunn in 1989

<u>Conclusion</u>:

Gunn is best choice for LO at present FET may have advantages in 1989.

LO STABILIZATION TECHNIQUES

- Lock to stable oscillator by means of
  (a) Phase-locked loop
    - Less hardware than multiplier, but slow to establish lock

  (b) Multiplier chain
    - Requires more hardware than PLL but possible more reliable, either approach gives good stability; ($\simeq 1x10^{-10}$), and low noise

- High Q invar cavity
  - Simpler than phase locked source but poorer stability

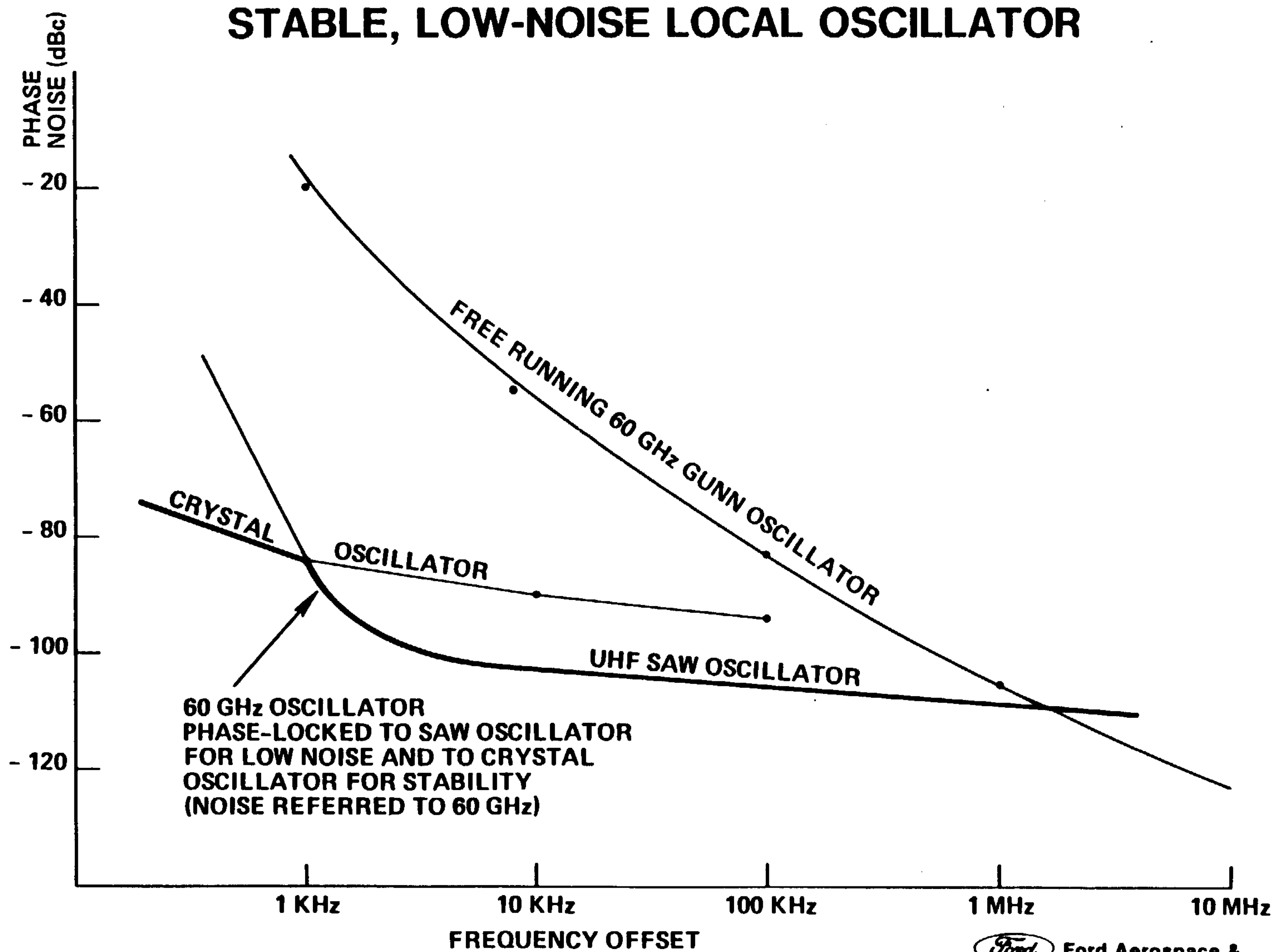
- Dielectric resonator
  - Very small, very lightweight
  - Simple and reliable
  - Good stability ($\simeq 1x10^{-7}$) but not as good as phase-locked

LOCAL OSCILLATOR CRITICAL REQUIREMENTS

- o Very good stability ($\simeq 10^{-10}$) short term stability
- o 10 - 20 milliwatts output power

<u>Conclusion</u>: Phase- locked source required for stability

STABLE, LOW-NOISE LOCAL OSCILLATOR



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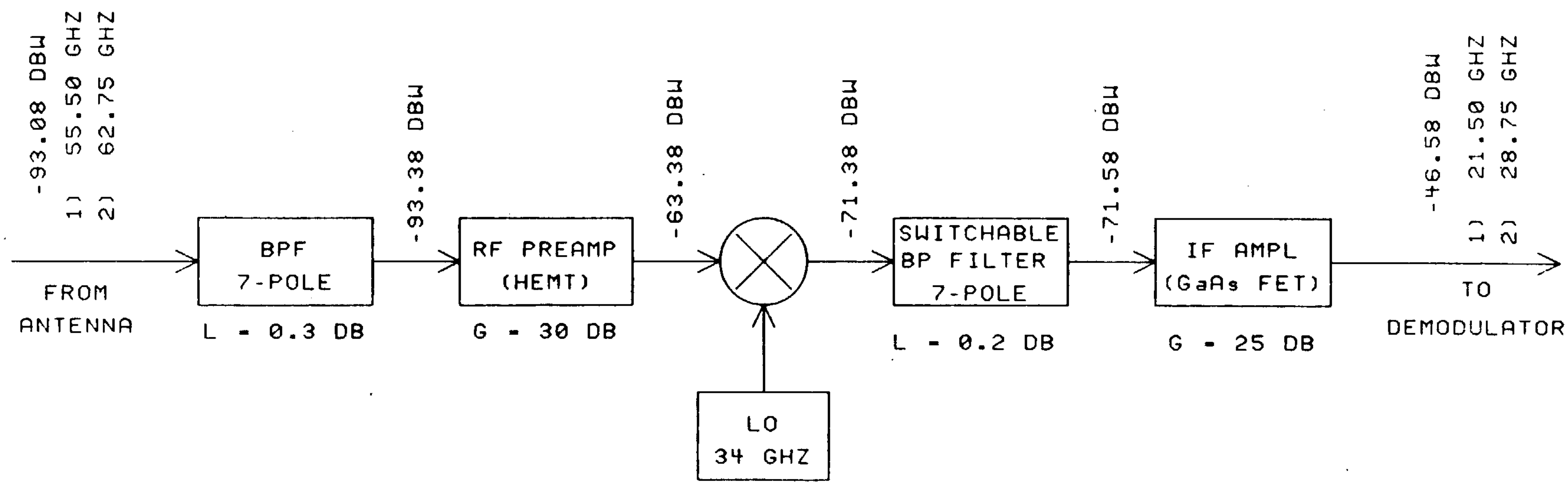

RF EQUIPMENT

ISL GEO-GEO RECEIVER SUBSYSTEM

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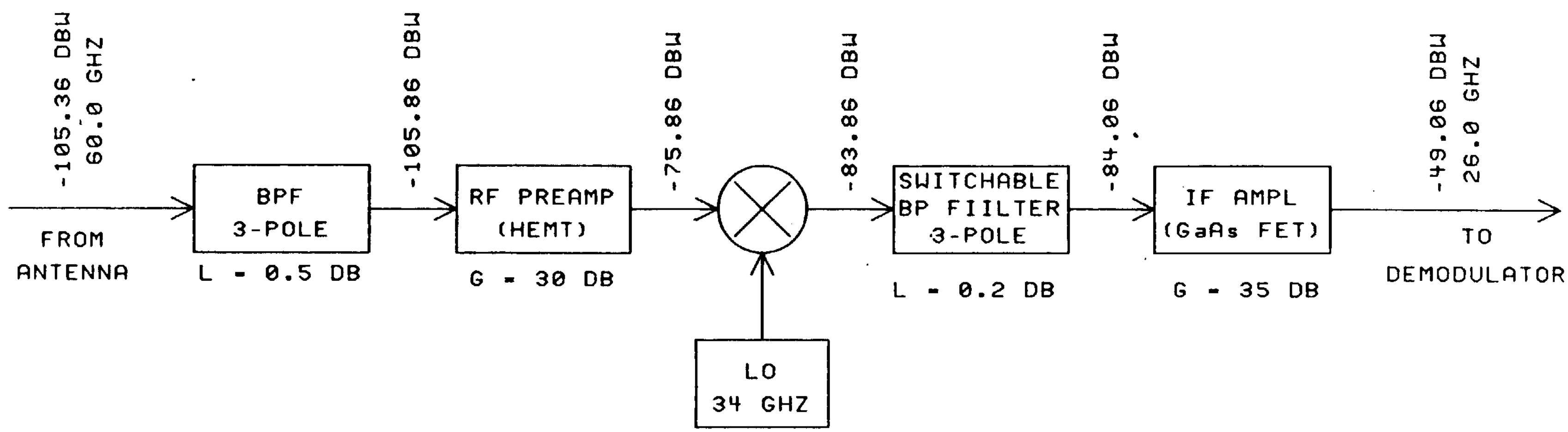
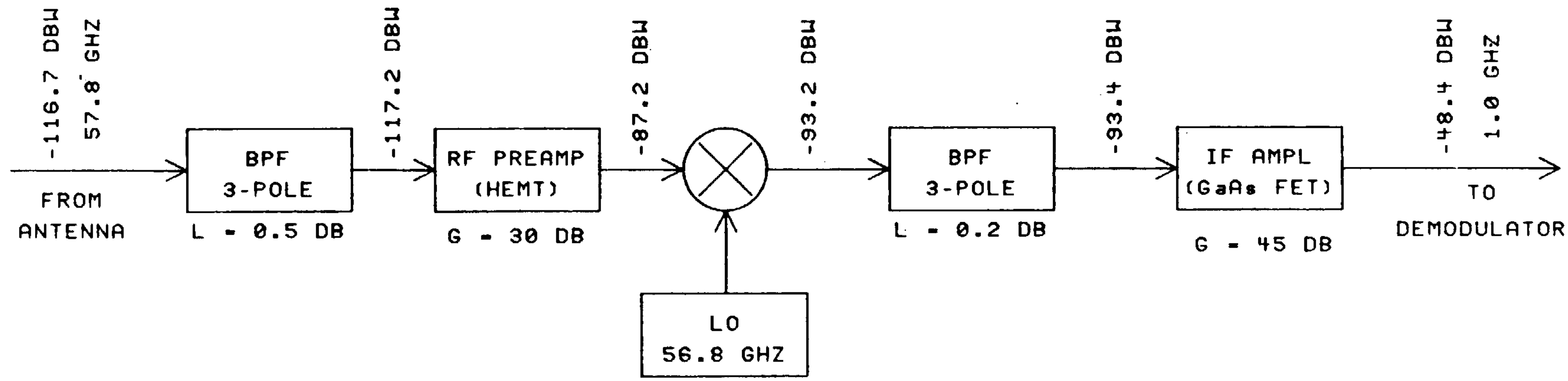


RF EQUIPMENT

ISL LEO-GEO RECEIVER SUBSYSTEM

Ford Aerospace & Communications Corporation



RF EQUIPMENT

ISL USER RECEIVER SUBSYSTEM

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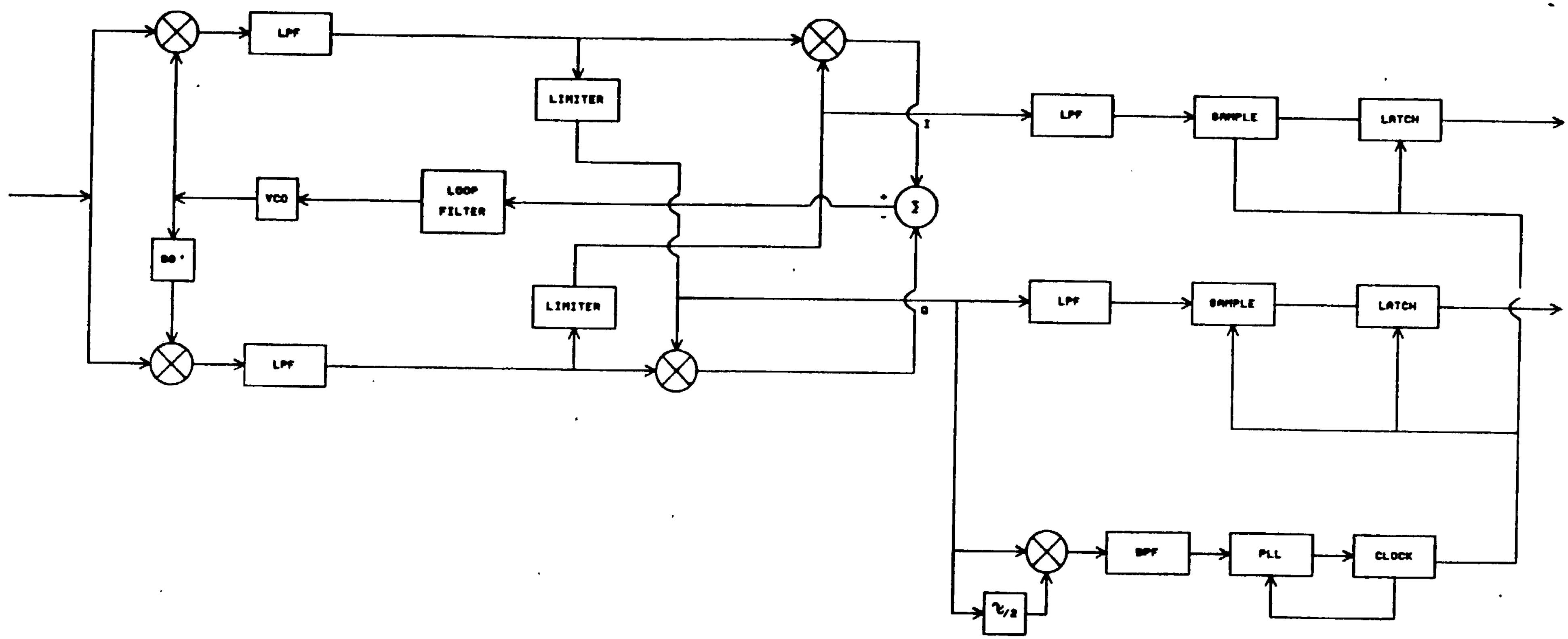
GEO-GEO DEMODULATOR

- 2 GB/s QPSK Demod
  - Double Costas Loop
  - Timing Recovery is Half Symbol Delay and Multiply
  - To Operate at 26 GHz
  - Required Performance Within 2.0 dB of theory at 10^{-6} BER
  - Is Similar to 2 GB/s Demod Built at FACC
    - Operates at 20 GHz
    - Within 2.5 dB of theory at 10^{-6} BER



QPSK DEMODULATOR SUBSYSTEM

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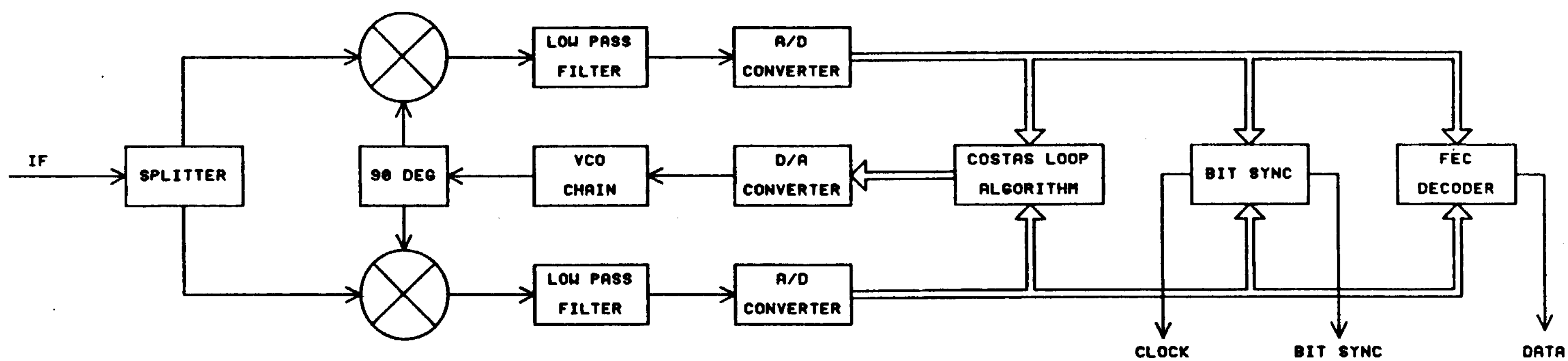
ORIGINAL PAGE IS
OF POOR QUALITY



VARIABLE DATA RATE DEMODULATOR

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LEO-GEO DEMODULATOR

- Variable Data Rate Demod
  - Hybrid Approach
  - Integrated FEC Decoder
  - Requires Development of Reliable 8-bit A/D Converter Capable of 150 M Conversions/second
  - Interaction Between Carrier and Clock During Acquisition Must be Further Investigated

TRANSMITTERS

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POWER DEVICES

- Solid state
  - IMPATT and Gunn effect
    - 2-terminal devices
    - Acts like negative resistance
    - Stable amplifier or ILO
  - FET
    - 3-terminal device
    - Heavy circulator not required
    - Better for broad band applications
- TWTA
  - Broad bandwidth
  - High gain
  - High efficiency

POWER DEVICES (CONTINUED)

- Injection locked oscillator
  - Higher gain and efficiency
    - Fewer stages
    - Reduced weight
  - Can reproduce only phase modulated signals
  - Free-running output present at all times unless turned off

- Stable amplifier
  - More suited to broad-band applications
  - Can reproduce high data rate phase modulated signals
  - Nonlinear

GUNN EFFECT DIODES

- Gallium Arsenide
  - Currently capable of about 100 mw at 60 GHz
  - Well-established technology
- Indium Phosphide
  - Better performance at millimeter wave lengths
    - Efficiency is double GaAs
    - Transferred electron effect valid to twice as high a frequency
    - Currently capable of 200 mw at 60 GHz
- Mature technology — not much more improvement expected by 1989

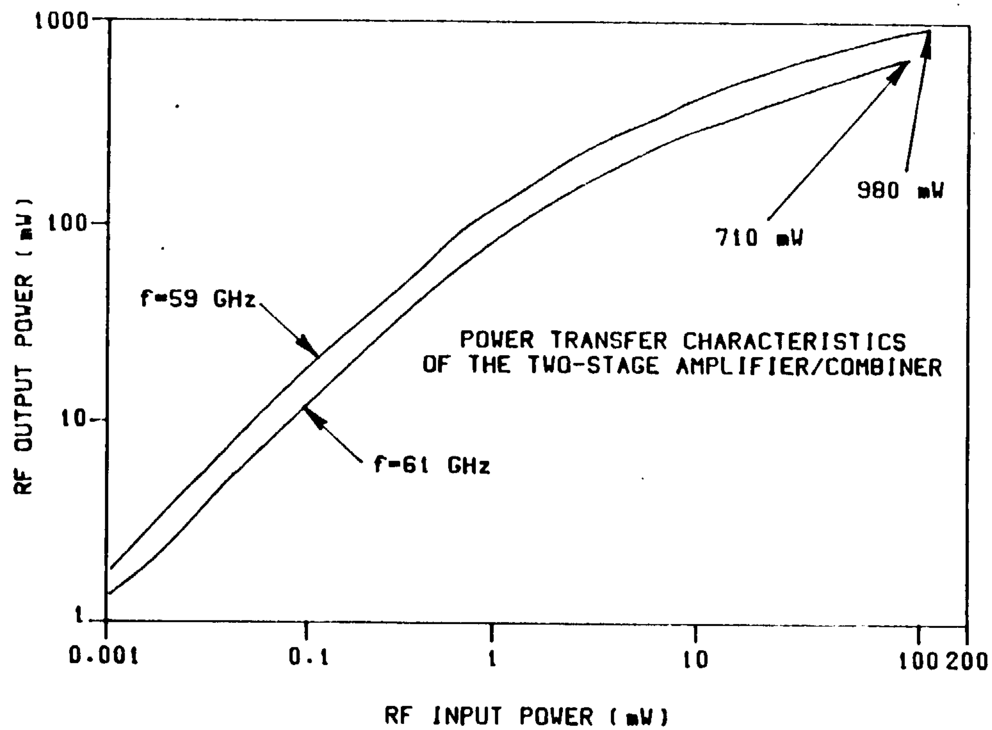
FETS

- At lower frequencies, efficiency better than IMPATT's
- Devices now operate at 69 GHz
- One watt output power at 20 GHz
- Although technology is advancing rapidly, FETS won't be usable in output stages of a 60 GHz power amplifier on a reliable basis by 1989.

IMPATT DIODES

- Gallium Arsenide
  - Superior efficiency and output power capability below 60 GHz
  - Can produce 1 W at 60 GHz
  - Expect to extend its superior efficiency to 60 GHz
  - Expect 2 W at 18% efficiency by 1989 (approximately 1.5 w for hi rel application)
- Silicon
  - Has produced 1 W at 60 GHz and several hundred milliwatts at higher frequencies
  - Less demanding processing requirements
  - Lower efficiency than GaAs
  - Expect 1.5 W at 8% efficiency by 1989 (approximately 1 W for hi rel)

POWER TRANSFER CHARACTERISTIC OF COMPLETE TWO-STAGE IMPATT AMPLIFIER



Reference: H.J. Kuno and D.L. English, "Millimeter Wave IMPATT Power Amplifier/Combiner", IEEE Trans. Microwave Theory Tech., Vol. MTT-24, p.p. 758-767, Nov. 1976.

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TWTA

- Technology well developed at lower frequencies
- Design problems at 60 GHz
  - Smaller size leads to:
    - Higher voltage stresses
    - Increased cathode current density
- Helical slow wave structure
  - Offers largest bandwidth
  - Currently produces 5 watts output power
- Coupled cavity structure
  - 75 W tube in development at 60 GHz
  - 3 GHz bandwidth
  - 40% efficiency

RELIABILITY

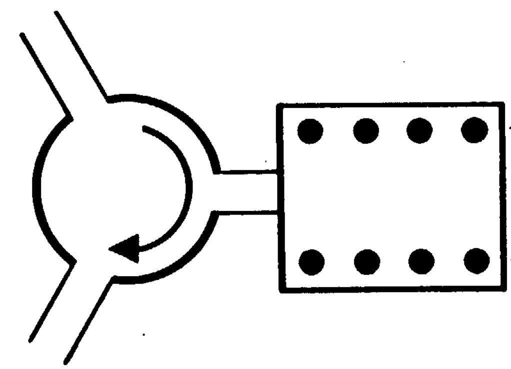
- TWTAs
  - Time dependent failure rate makes reliability prediction inexact (actual life data is needed, accelerated life tests are misleading)
  - Failure rate likely no better than 20,000 FITs
- IMPATT amplifier
  - Life very dependent on junction temperature (therefore on the number of diodes used to achieve desired power level)
  - More IMPATT life data is required, however some data indicates 1000 FITs at 240°C junction temp

POWER COMBINING TECHNIQUES

<u>Circuit Level</u>

- N-way Combiners
  - Resonant combiner
    - At 60 GHz, cavity is small, limiting number of diodes which can be used
    - Bandwidth less than 3%
- Radial combiner
  - Broad bandwidth
  - Waveguide type has low loss
  - Microstrip type is smaller but lossier
- Hybrid couplers
  - Efficient
  - Broad band
  - Becomes unwieldy and inefficient for N>4

POWER COMBINING TECHNIQUES (CONTINUED)



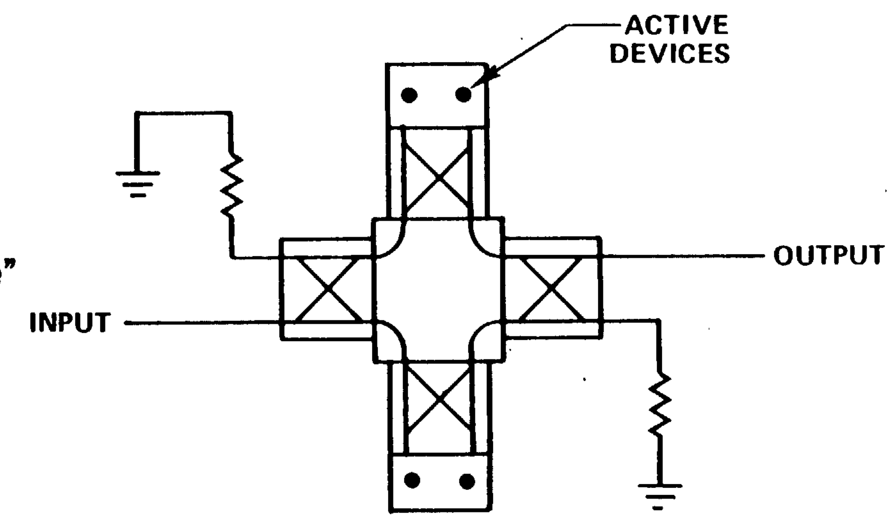
N-WAY

- Advantage:
  - Small
  - Light
  - Efficient
- Disadvantage - at high frequencies either:
  - Circuit becomes small, limits number of devices
  - If circuit is not small, supports many modes, becomes unstable
  - Narrow band (3%)

POWER COMBINING TECHNIQUES (CONTINUED)

Hybrid Combiner

- Advantages
  - Broad band (5%)
  - Straight forward "brute force" approach
- Disadvantage
  - Becomes large, heavy and inefficient when number of devices is large

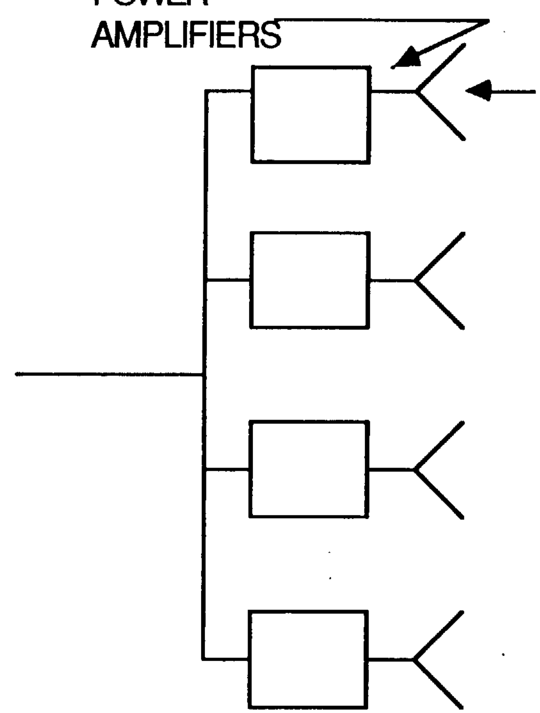


4 DEVICE HYBRID COMBINER

POWER COMBINING TECHNIQUES (CONTINUED)

SPATIAL COMBINING

- o Advantage
  - Suitable for phased array
  - Efficient
- o Disadvantage
  - May be unnecessarily complex for some applications
  - Element spacing



TWTA STATUS AND PROJECTIONS
(60 GHz)

YEAR	TYPE	OUTPOWER	EFFICIENCY	WEIGHT
1985	Helix	5 W	15%	3.3 lb
1989	Coupled Cavity	75 W	40%	15 lb
1995	Helix	10 W	20%	3.3 lb

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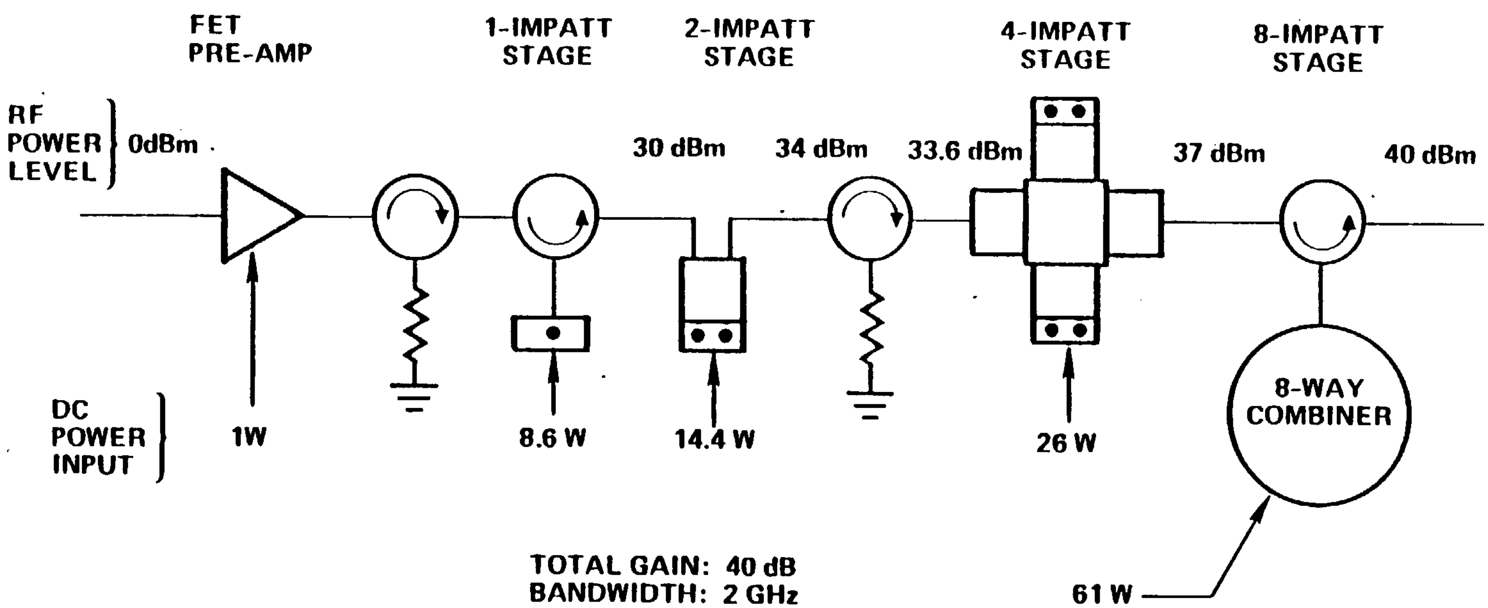
COMPARISON CANDIDATE 10 WATT POWER AMPLIFIERS

CHARACTERISTIC	TWTA	IMPATT (Assuming 1.5 W devices)	IMATT (Assuming 0.5 W devices)
Gain	38 dB	38 dB	38 dB
Bandwidth	2 GHz	2 GHz	2 GHz
Power Output	10 W	10 W	10 W
DC Power Input	67 W	111 W	200 W
Efficiency	15%	9%	5%
Weight Of RF Amplifier	6.6 lbs.	1.6 lbs.	3.7 lbs.
Weight Of DC/DC Converter	6.6 lbs.	3.3 lbs.	6.6 lbs.
Total Weight	13.2 lbs.	4.9 lbs.	10.3 lbs.
Power Into DC/DC Converter	80 W	130 W	235 W
Reliability	20,000 FIT's	*	*

*Insufficient reliability data exists. Current estimates are 500 FIT's - 1,000 FIT's per diode. The data does not differentiate IMPATT diode failure rates for power ratings or application frequencies.

10/7.5 WATT IMPATT AMPLIFIER



TOTAL GAIN: 40 dB
BANDWIDTH: 2 GHz
POWER OUTPUT: 10 W
DC INPUT: 111 W
EFFICIENCY: 9%
WEIGHT: 1.6 LB

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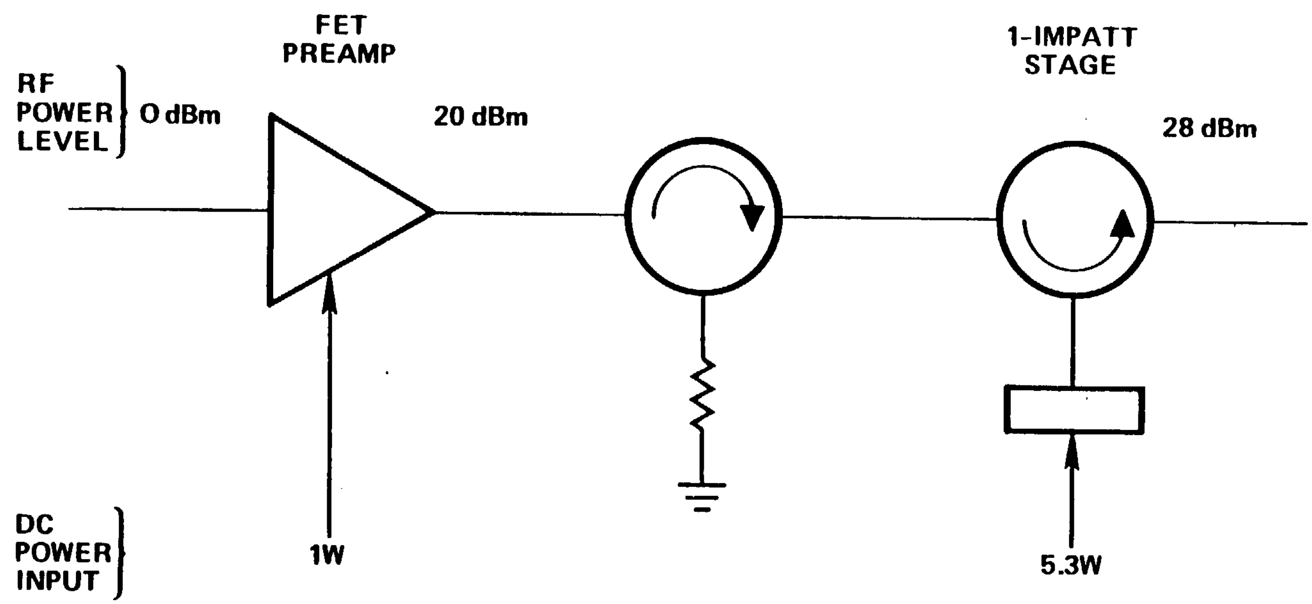
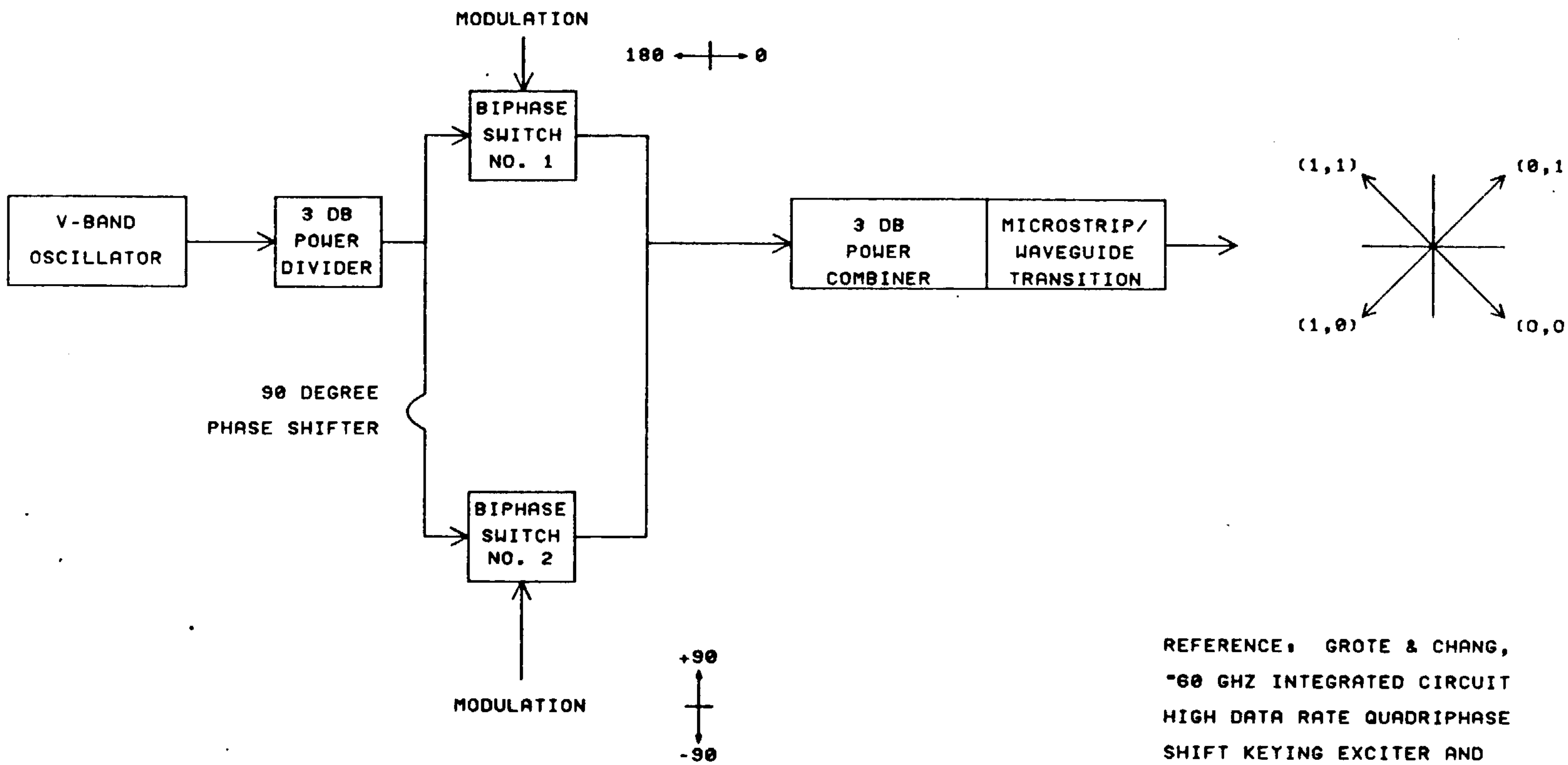
0.6 WATT IMPATT AMPLIFIER



TOTAL GAIN: 28 dB
BANDWIDTH: 1 MHz
POWER OUTPUT: 0.6 W
DC INPUT: 6.3 W
EFFICIENCY: 9.5%
WEIGHT: ~ 0.25 LB



60 GHZ QPSK MODULATOR

REFERENCE: GROTE & CHANG, "60 GHZ INTEGRATED CIRCUIT HIGH DATA RATE QUADRIPHASE SHIFT KEYING EXCITER AND MODULATOR", IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOLUME MTT-32, NO. 12, P 1113, DECEMBER 1984

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RELIABILITY

- o Reliability is one of the most important parameters at this time.
- o Data rate is tied directly to attainable reliability levels.
- o Improved parts characterization is essential for transmitters.
- o IMPATT reliability is still the largest unknown.
- o TWTA's (replacement for IMPATT's) do not appear to provide a great reliability benefit.
- o Reliability estimates for other components are not expected to charge greatly over the next few years.
- o Complexity of antenna control electronics leads to high failure rates.
- o Redundancy brings improvements but the optimum solution is integrated electronics approach.
- o Techniques for hardware integration cross-strapping must be improved to achieve reliability goals within physical constraints.

MECHANICAL DESIGN

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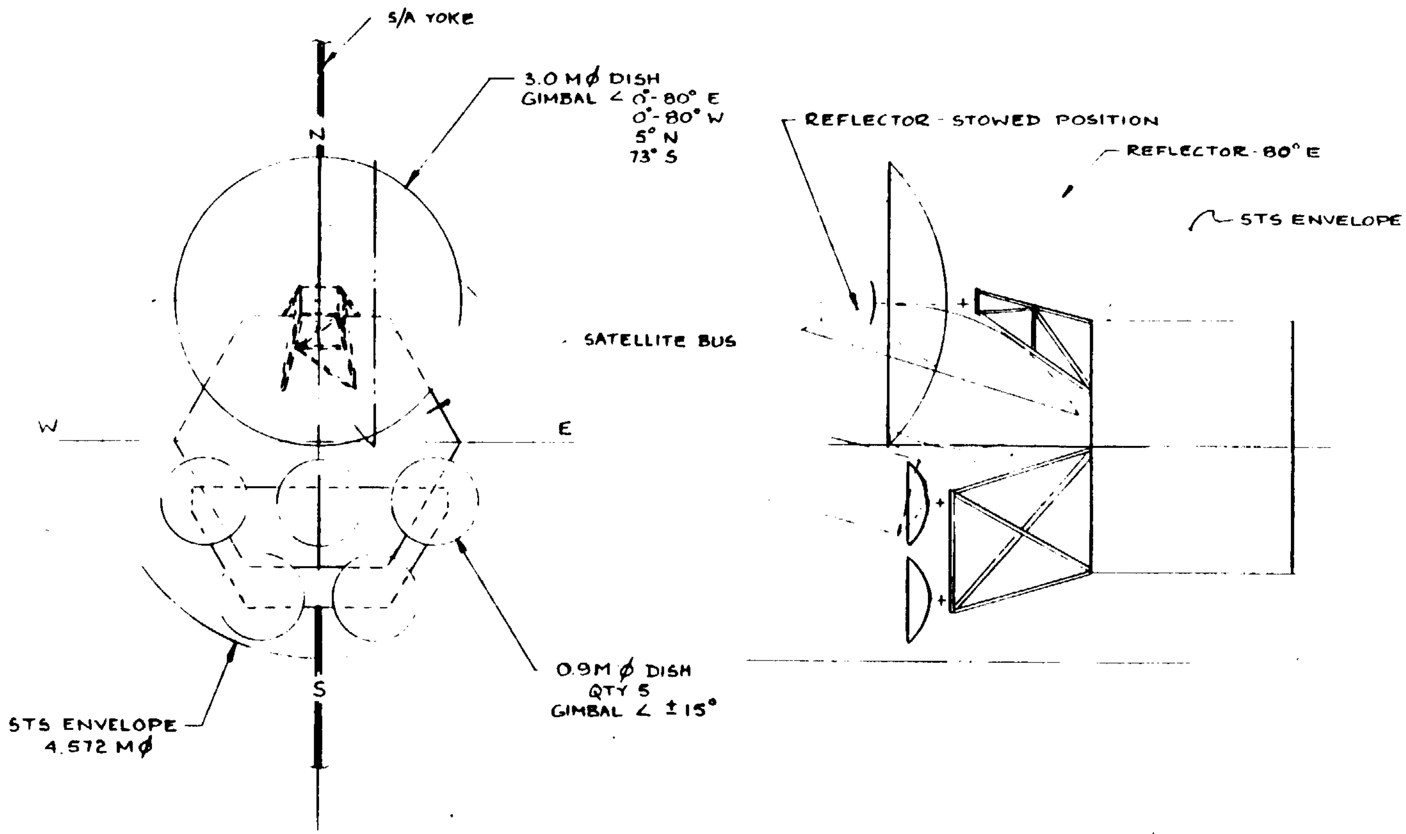
60 GHz ISL DEFINITION STUDY BASELINE

- Structural concept
- Thermal control concept
- Electromechanical device
- Contamination issues

TDAS LAYOUT



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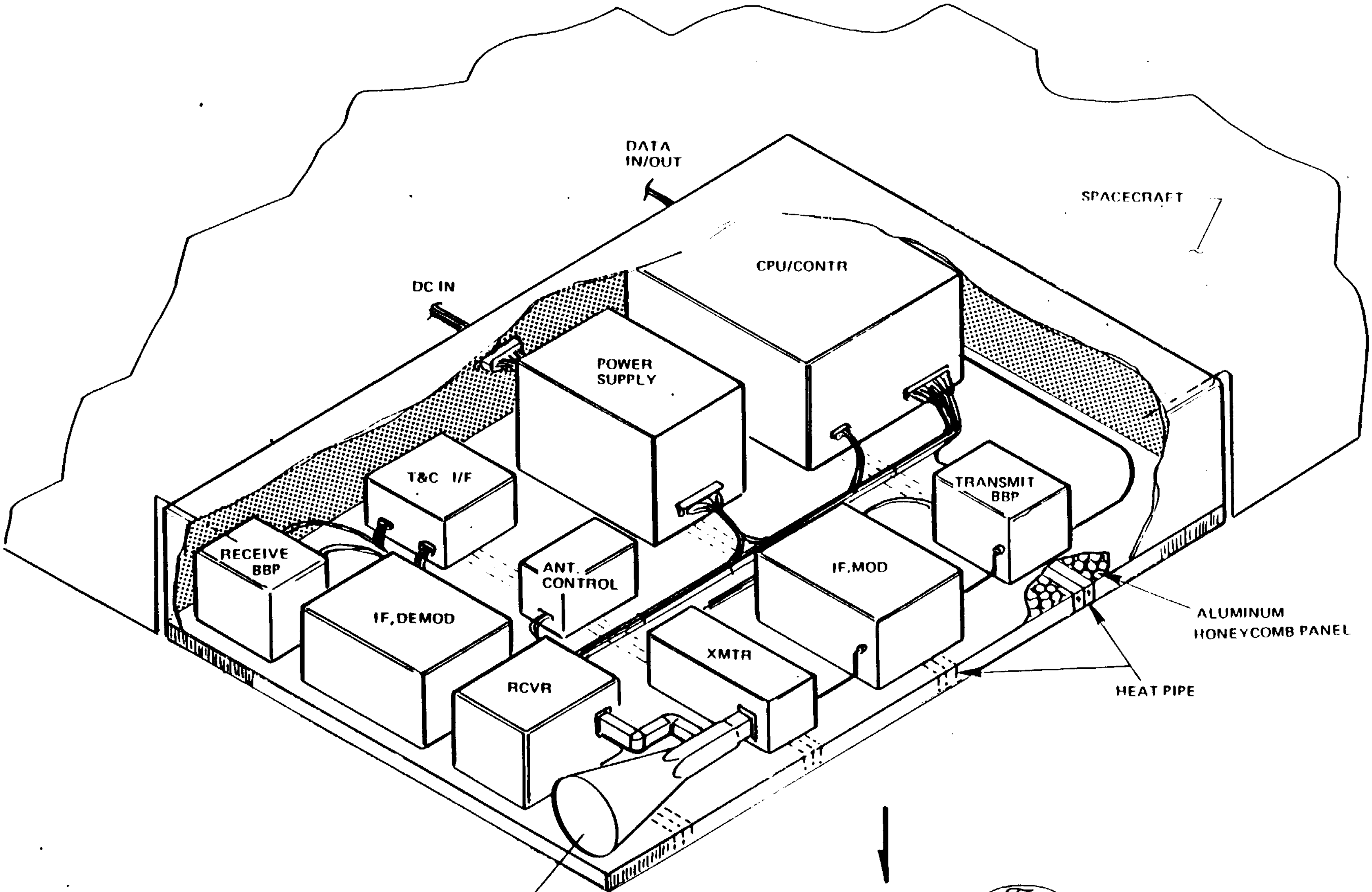
ELECTRONICS MODULE CONCEPT



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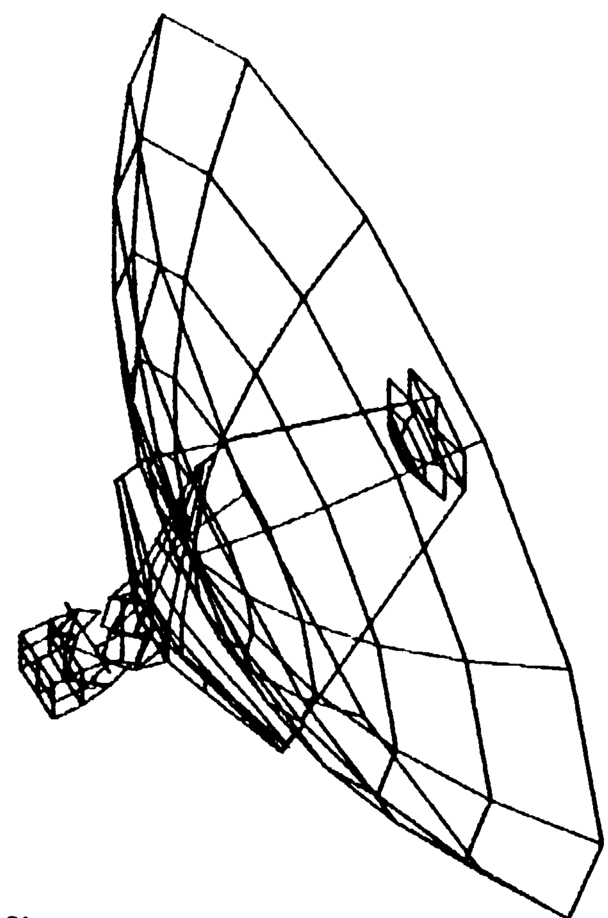
3 METER BASELINE ANTENNA CONFIGURATION



NASTRAN MODEL

211 ELEMENTS

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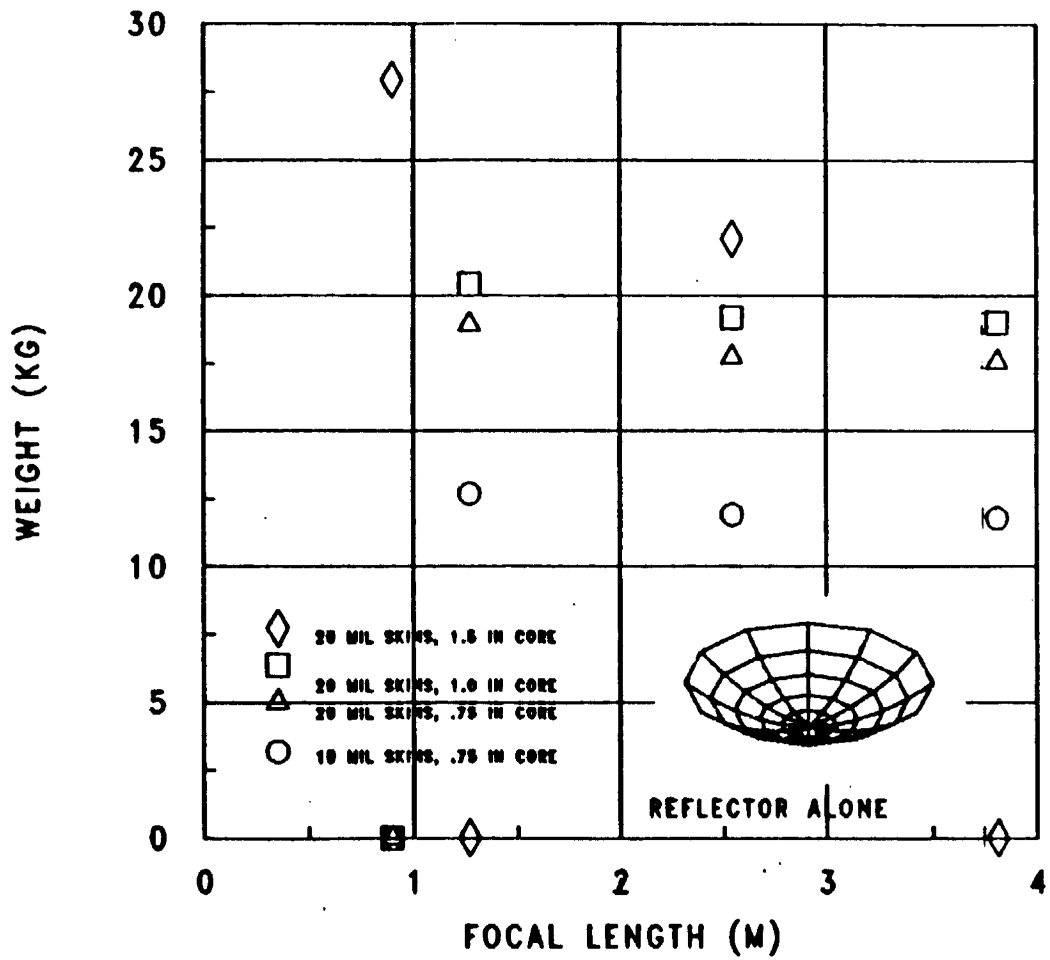
3 METER MAIN REFLECTOR MASS TRADEOFF



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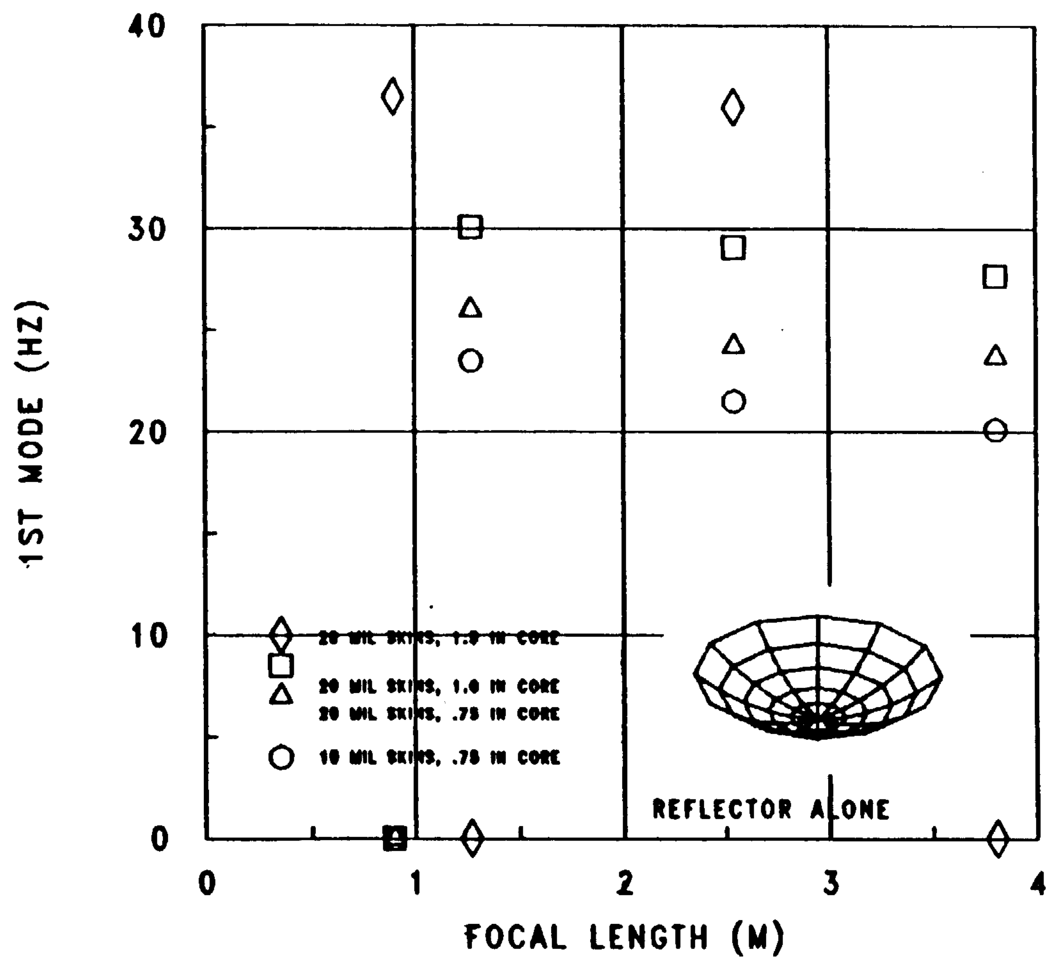
3 METER MAIN REFLECTOR RESONANCE TRADEOFF



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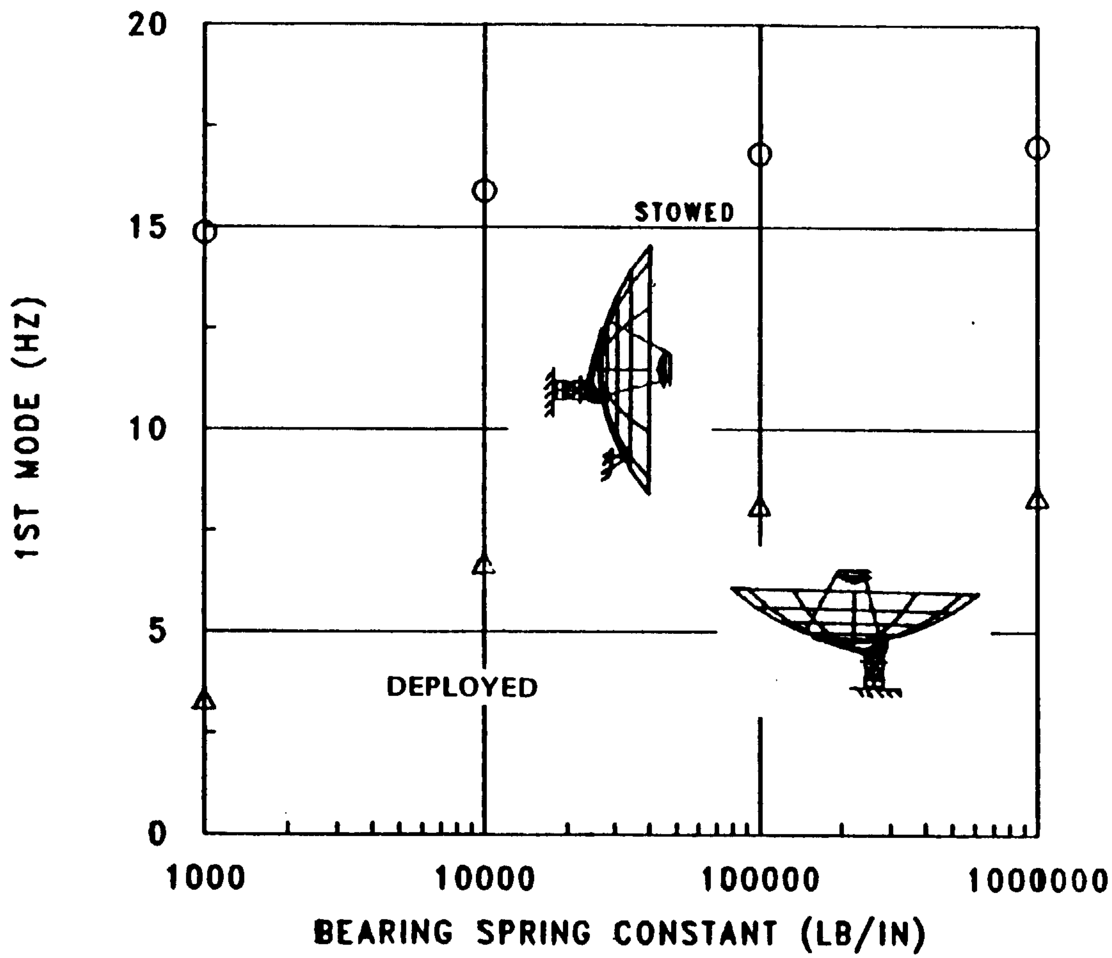
3 METER ANTENNA SYSTEM RESONANCE



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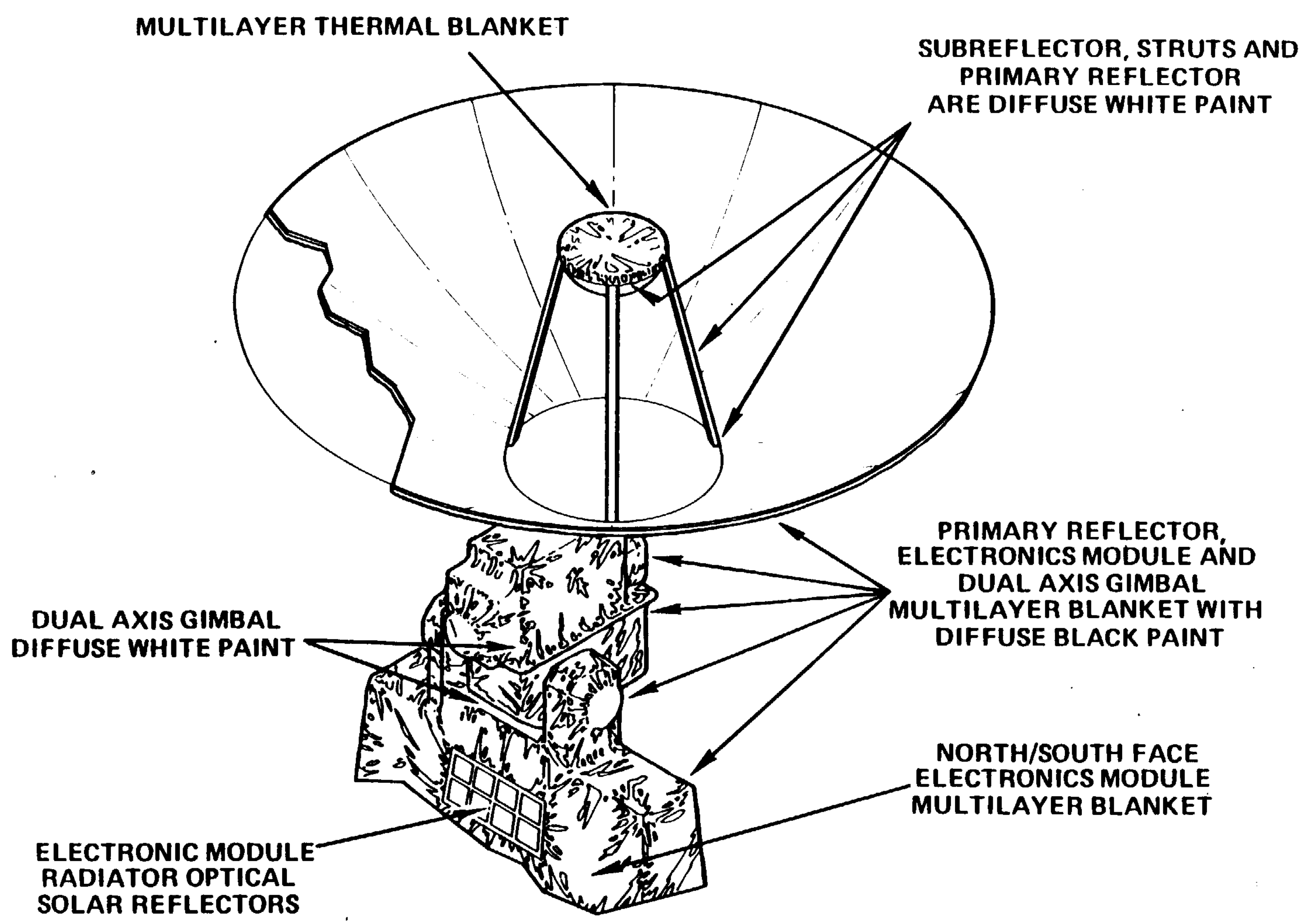

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THERMAL CONTROL PROPERTIES

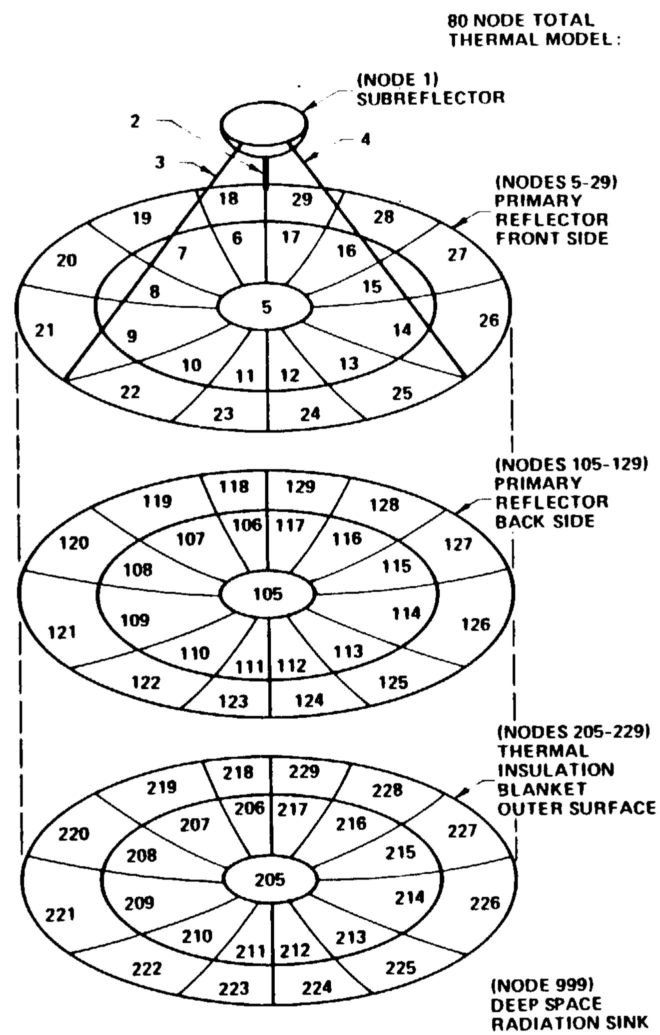
	BOL a	EOL a	EMITTANCE
White Paint	0.20	0.60	0.85
Aluminized Kapton (I mil)	0.39	0.52	0.53
Black Paint	0.90	0.90	0.85
Optical Solar Reflectors	0.08	0.21	0.80
		Effective Emittance	
Multilayer Blankets, Aluminized Kapton Outer Surface		0.015	
Multilayer Blankets, Black Paint Outer Surface		0.05	

THERMAL CONTROL PROPERTIES

	BOL_a	EOL_a	BOL/EOL_e
White Paint	0.20	0.60	0.85
Aluminized Kapton (1 mil)	0.39	0.52	0.53
Black Paint	0.90	0.90	0.85
Optical Solar Reflectors	0.08	0.21	0.80

	Effective Emittance
Multilayer Blankets, Aluminized Kapton Outer Surface	0.015
Multilayer Blankets, Black Paint Outer Surface	0.05

PRELIMINARY THERMAL MODEL FOR 3 METER REFLECTOR ASSEMBLY



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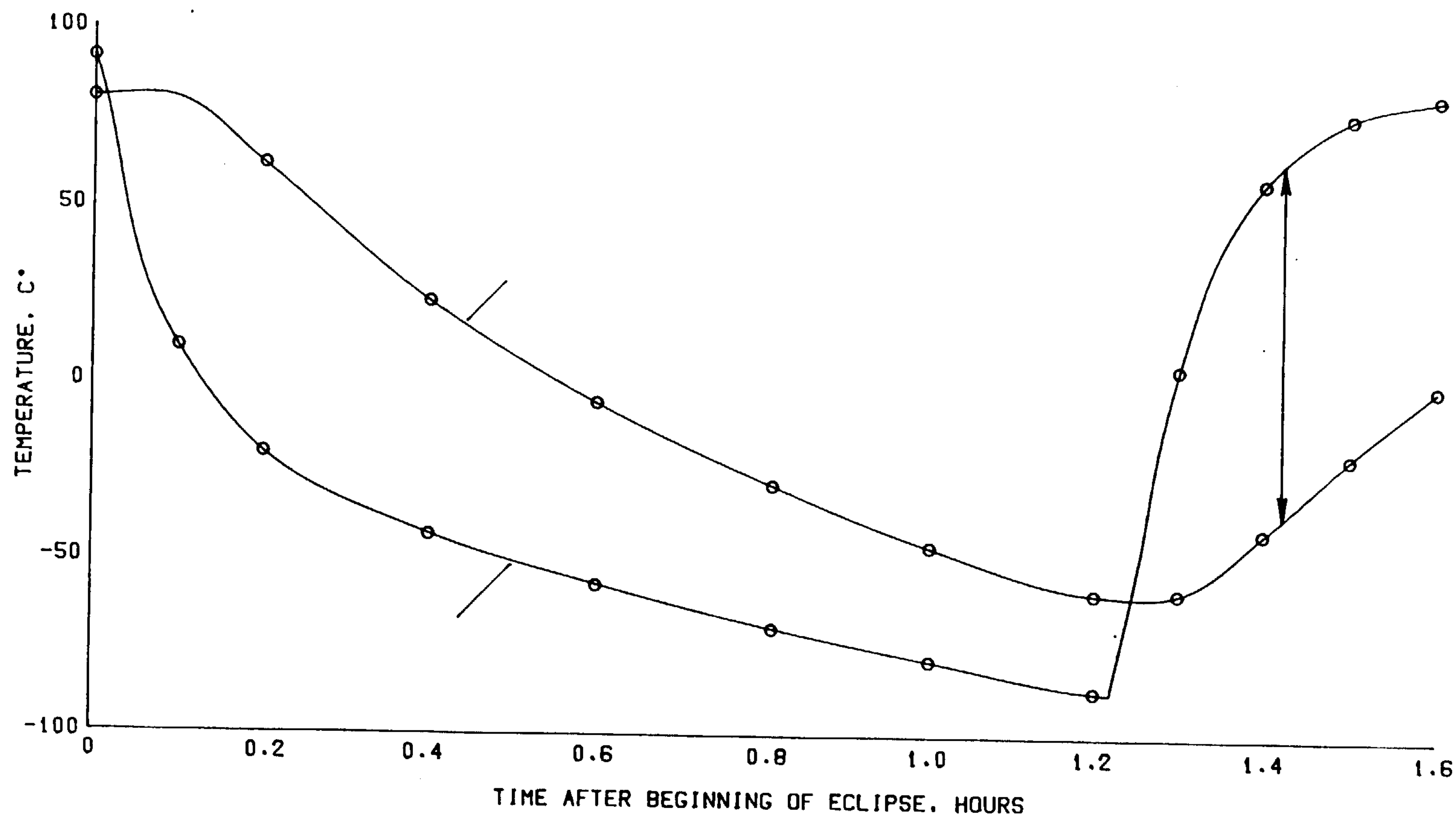
60 GHz MAIN REFLECTOR TIME VS. TEMPERATURE RESPONSE FOR ECLIPSE AND POST ECLIPSE



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TEMPERATURE PREDICTION SUMMARY

	MAIN REFLECTOR			SUBRFLCTR	STRUTS	
Solar Illumination Case	max temp(^{o}c)	min temp(^{o}c)	max frt to bck grad (^{o}c)	sbrflctr temp (^{o}c)	max temp(^{o}c)	min temp(^{o}c)
1. Full Front (Concave) Sun	94	-11	17	85	42	42
2. I/2 Front (Concave) Sun	87	-9	10	28	15	-41
3. Full Back (Convex) Sun	-112	-134	20	-160	-156	-156
4. I/2 Back (Convex) Sun	-121	-189	15	-179	-163	-193
5. Side Sun (Perp. to focal axis)	-143	-192	9	-79	-79	-80

ELECTRONIC MODULE THERMAL CONTROL*
TRADEOFF GEO/GEO, GEO/LEO

Characteristic	OSR/ Radiator	OSR/ Louver	OSR/ Heat Pipe
Heat sink mass (kg)	0.57	0.57	0.00
Louver mass (kg)	0.00	1.48	0.00
Heat pipe mass (kg)	0.00	0.00	0.34
Δ OSR mass (kg)	0.00(1)	0.00(1)	0.00(1)
Δ Panel mass (kg)	0.00(2)	0.00(2)	0.15
Δ Mass to insulated panel (kg)	0.57	2.05	0.49
Radiator area (m^2)	0.53	0.58	0.37
Equipment off heater power ratio (dimensionless)	1.42	0.06	1.00
Heat rejection W/cm^2	0.022	0.020	0.030

Notes:
1. $(mass/area)_{OSR} = (mass/area)_{blankets}$
2. Radiator area does not dictate panel size

* Conditions; sun angle = 23.5°, winter solstice solar intensity, radiator temperature = 35°C, total dissipation = 65 W

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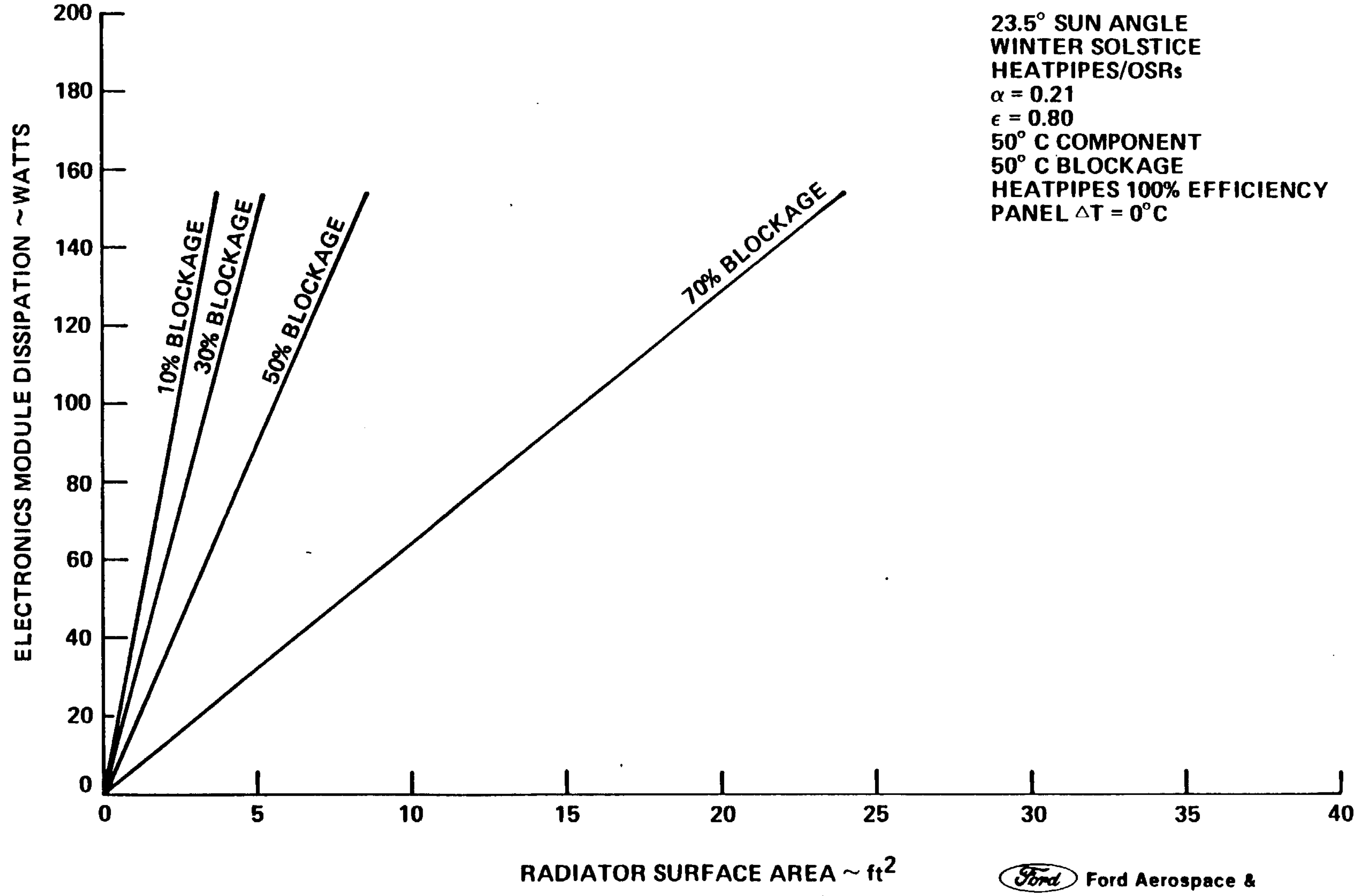
RADIATOR SURFACE AREA REQUIREMENTS
23.5 DEGREE SUN ANGLE



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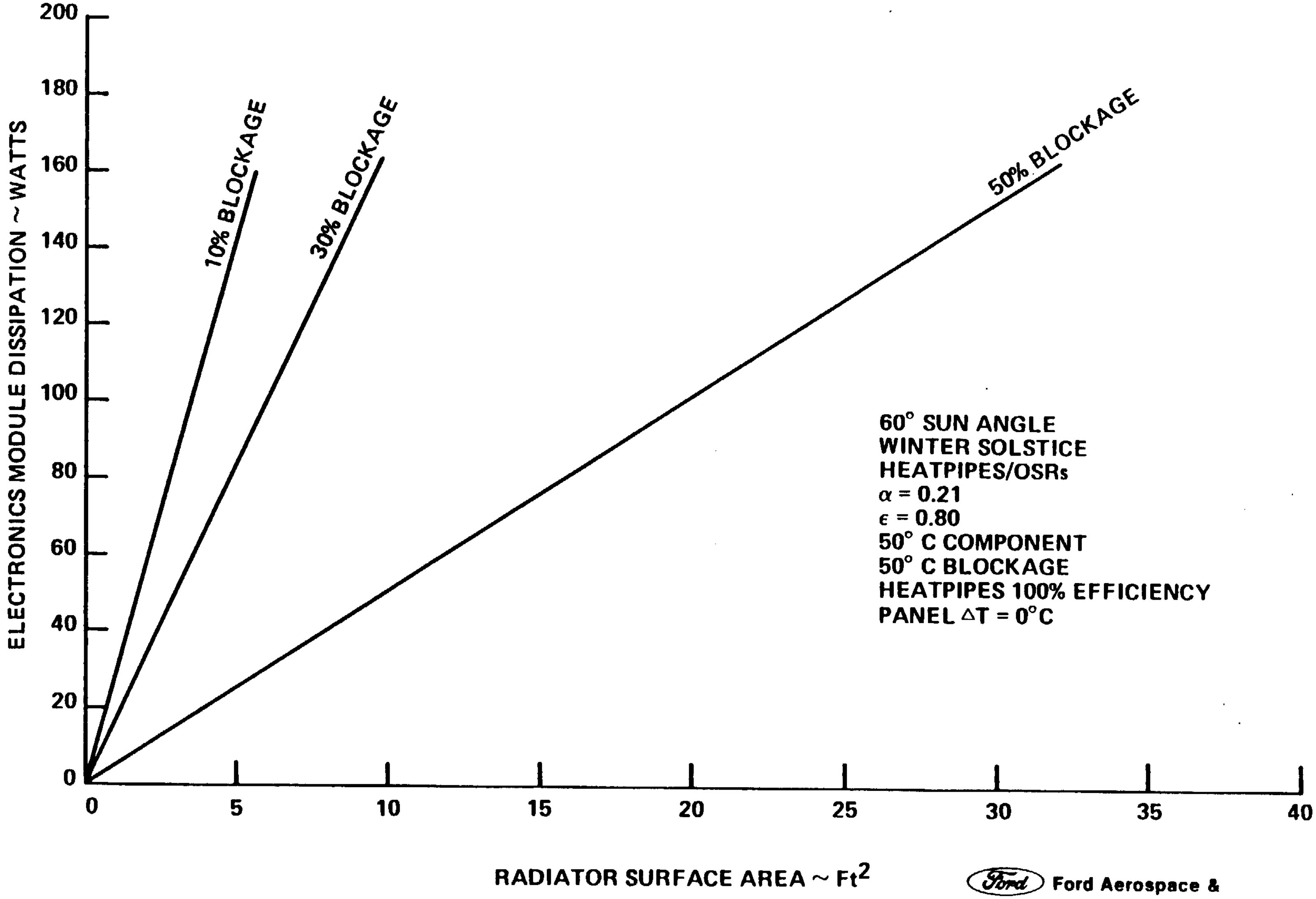
RADIATOR SURFACE AREA REQUIREMENTS
60 DEGREE SUN ANGLE



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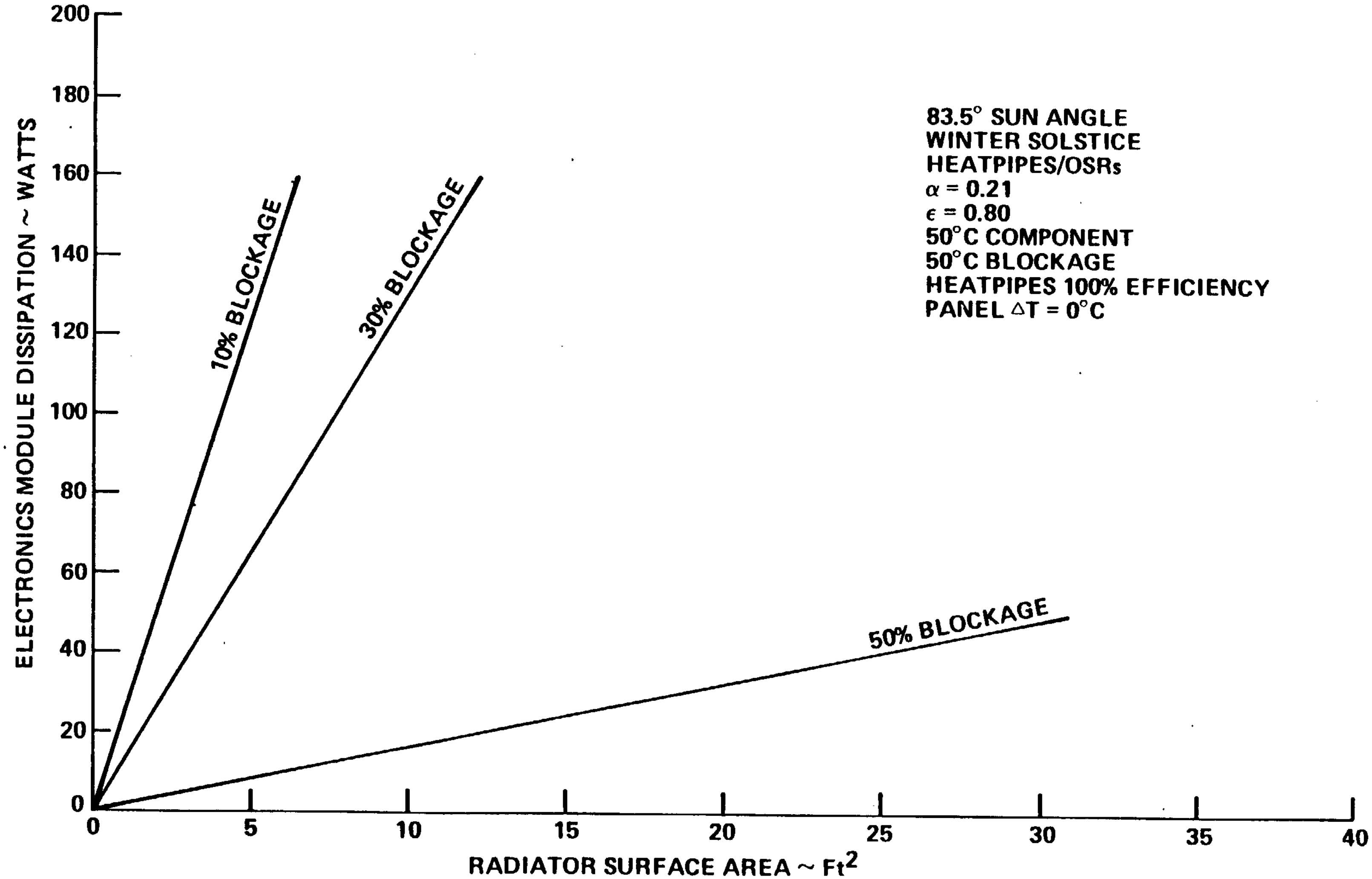
RADIATOR SURFACE AREA REQUIREMENTS
83.5 DEGREE SUN ANGLE



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THERMAL DISTORTION FOR MAIN REFLECTORS

- o Allowance for design is 0.001 inches.

- o Calculated Distortions for Effective Coefficient of Expansion = 0.754×10^{-6} in/in-^oC

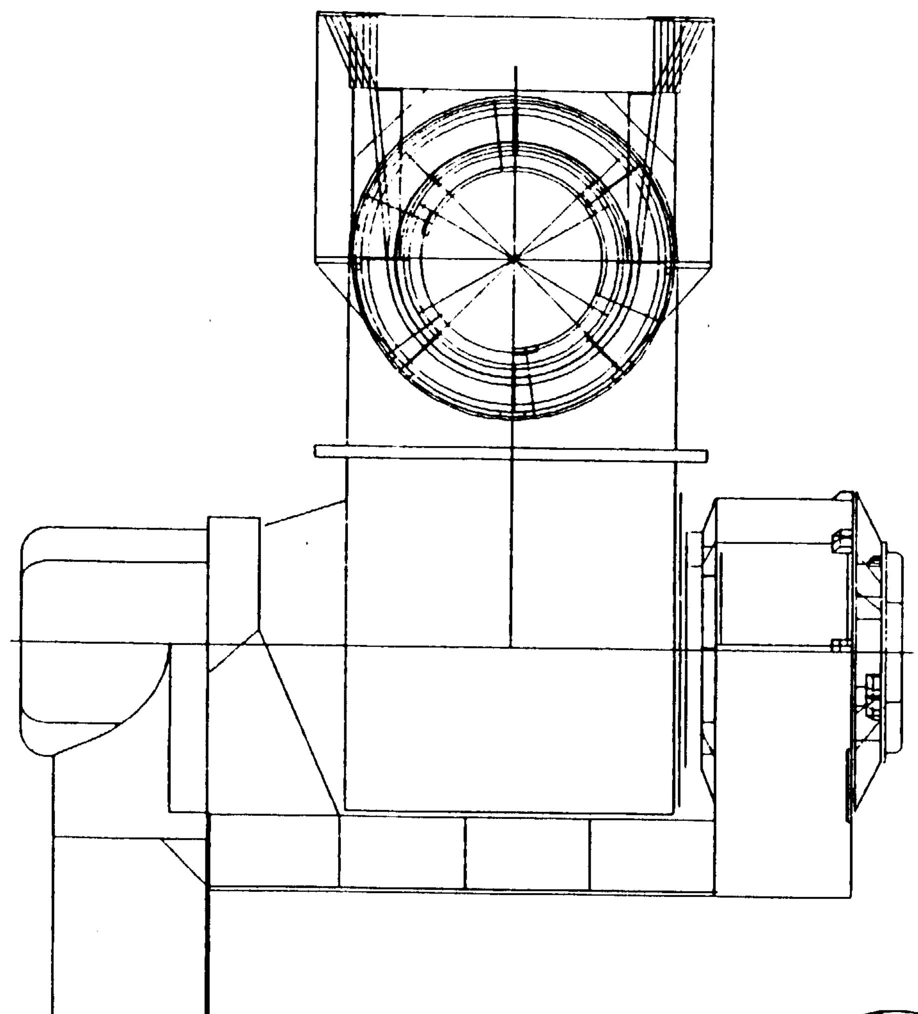
THERMAL CASE	REFLECTOR RMS DISTORTION, INCHES
1. Full sun normal to front (concave) side of main reflector (E.O.L.).	0.00012
2. Full normal sun on 1/2 of main reflector frontside (E.O.L.).	0.00021
3. Full sun normal to back (convex) side of main reflector.	0.00035
4. Full normal sun on 1/2 of main reflector backside.	0.00042
5. Full side sun. (Solar vector normal to antenna focal axis).	0.00047
6. Worst case frontside to backside gradient after eclipse exit (taken from a transient analysis).	0.00017

- o Well within design allowance.

POWER, SIZE AND WEIGHT SUMMARY

	GEO-GEO	LEO-GEO
Electromechanical and R.F. Components Mass	71.3 Kg	188.0 Kg
Radiators And Heat Pipes Mass	8.7 Kg	21.3 Kg
Truss, Blankets, Brackets Etc. Mass	5.0 Kg	25.0 Kg
TOTAL MASS	85.0 Kg	234.3 Kg
Radiator Area	1.2 Sq. M	3.3 Sq. M
Thermal Dissipation	234 W	538 W
D. C. Power In	244 W	541 W

DUAL AXIS GIMBAL ASSEMBLY



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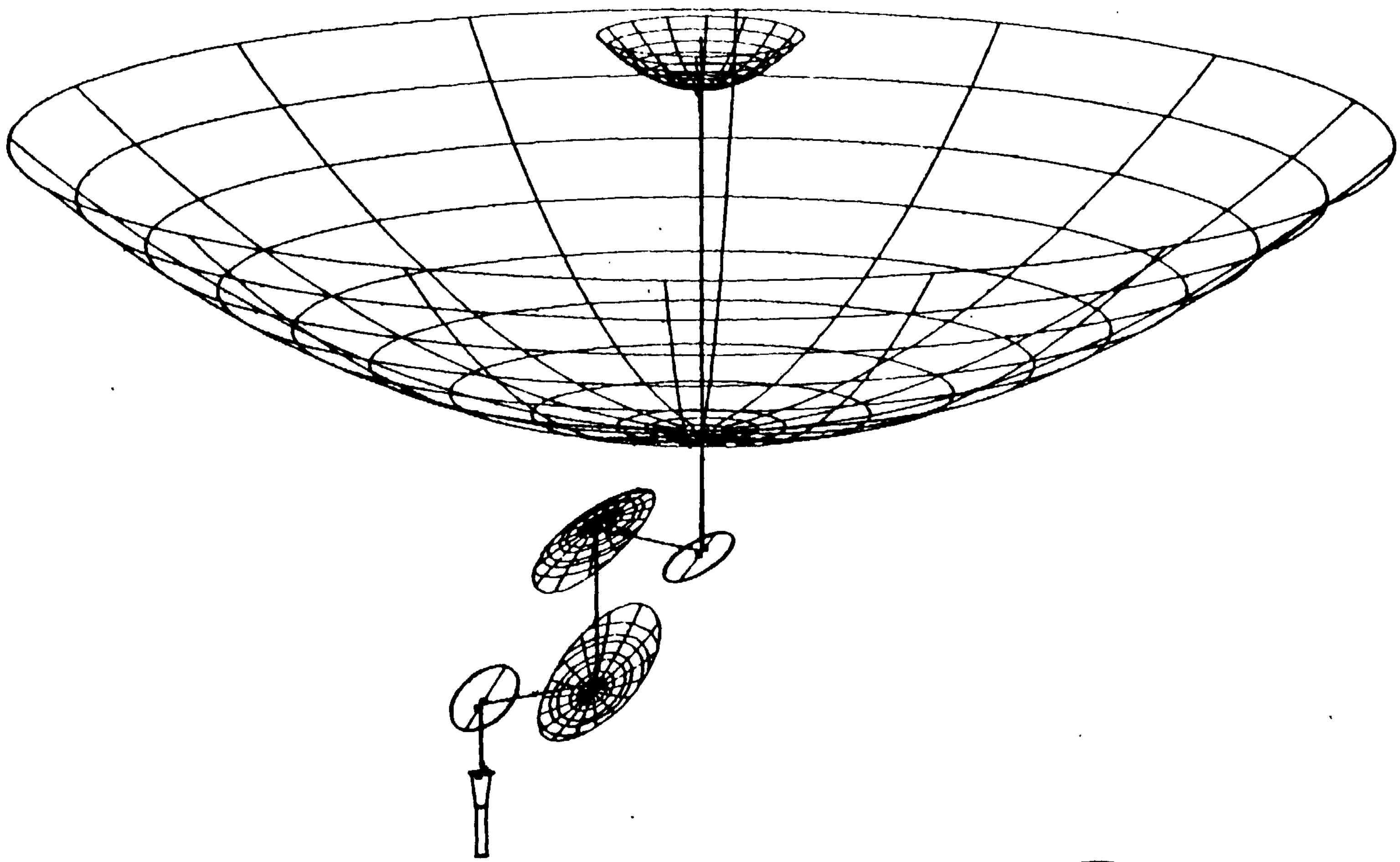
RF PATH TRANSPONDER TO ANTENNA



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GIMBAL CHARACTERISTICS

PARAMETERS	GIMBAL CROSSLINK MISSION		
	GEO-LEO	LEO-GEO	GEO-GEO
MECHANISMS/SPACECRAFT	5	1	1
ANTENNA DIAMETER	0.9 METER	1.4 METER	3 METERS
ANGULAR RANGE, ELEVATION	+/- 20 DEG.	+/- 90 DEG.	+/- 10 DEG.
AZIMUTH	+/- 20 DEG.	+/- 90 DEG.	+/- 35 DEG.
MAXIMUM SLEW RATE	5.0 DEG/SEC	5.0 DEG/SEC	2.0 DEG/SEC
MAXIMUM ACQUISITION TIME (3)	1 MIN.	1 MIN.	1 MIN.
COMMON CHARACTERISTICS			
ANGULAR RESOLUTION	0.011 DEG.		
MAXIMUM TRACKING RATE	6.0 DEG/MIN.		
GIMBAL MASS.	12.7 KG		
POWER CONSUMPTION	9 W AVG/32 W PEAK		

60 GHz LINK SUBSYSTEM POINTING ERRORS (SUM)

ERROR SOURCE	OPEN LOOP MODE ERROR CONTRIBUTIONS (DEGREES)		CLOSED LOOP MODE ERROR CONTRIBUTIONS (DEGREES)	
	AZIMUTH	ELEVATION	AZIMUTH	ELEVATION
CONSTANT TERMS	0.0613	0.0613	0.0000	0.0000
LONG TERMS	0.0254	0.0254	0.0112	0.0112
SHORT TERMS	0.0300	0.0300	0.0300	0.0300
DAILY TERMS	0.0537	0.0537	0.0197	0.0197
TOTAL ERROR (DEGREES)	0.1772	0.1772	0.0609	0.0609

DISTURBANCE MOMENTUM SUMMARY

Disturbance Type	Peak Error Momentum (Az, El*)
GEO-GEO/SLEW	±0.9 Nms
GEO-GEO/TRACK	±0.045 Nms
GEO-LEO/SLEW	±0.16 Nms
GEO-LEO/TRACK	±0.035 Nms
LEO-GEO/SLEW	±0.25 Nms
LEO-GEO/TRACK	±0.045 Nms

*Z-axis (yaw) momentum is relatively smaller in all cases

RELATING DISTURBANCE MOMENTUM TO BODY RATES

- Spacecraft body rate:
  - Without compensation $W_{s/c} = H_{dist.}/I_{s/c}$*
  - With compensation $W_{s/c} = 0.1\ H_{dist.}/I_{s/c}$*

Spacecraft body rates for an Intelsat V-size spacecraft*

Case	Uncomp. $w_{s/c}$ (°/sec)	Compensated $w_{s/c}$ (°/sec)
GEO-GEO/Slew	±0.026	±0.0026
GEO-GEO/Track	±0.0013	±0.00013
GEO-LEO/Slew	±0.0046	±0.00046
GEO-LEO/Track	±0.0010	±0.0001
LEO-GEO/Slew	±0.0072	±0.00072
LEO-GEO/Track	±0.0013	±0.00013

*$I_{s/c} \simeq 2000$ kg m^2

CONCLUSIONS

- o Antenna tracking rates (ave):
  - GEO/GEO = 0
  - GEO/LEO = 0.007^{o}/s
  - LEO/GEO = 0.067^{o}/s

- o GEO-GEO disturbances are large with or without compensation. May not be important for operational/frequency reasons.

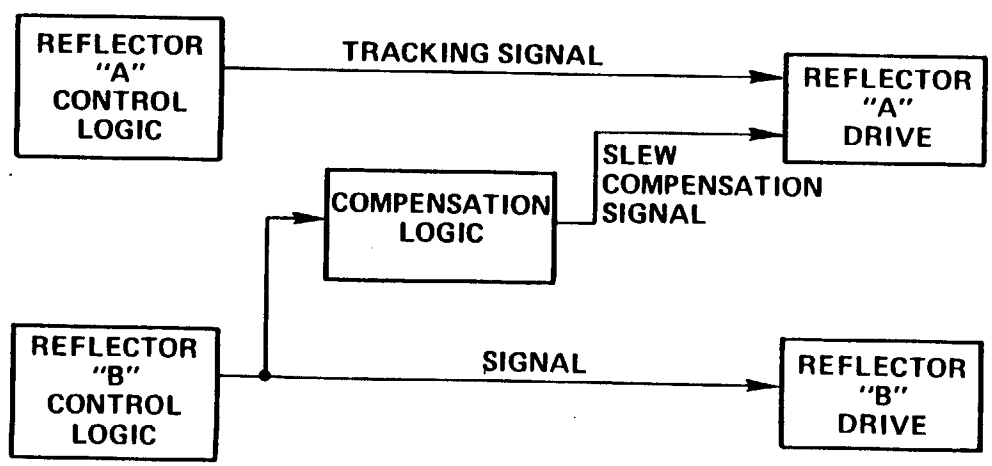
- o GEO-LEO slew is significant relative to antenna tracking rate, without compensation. Both slew and track disturbances are okay with compensation (for no more than two antennas slewing at same time).

- o LEO-GEO has high antenna tracking rates; motion compensation may not be required to keep disturbance rates well below tracking rate.

REFLECTOR MOTION COMPENSATION CONCEPT

Scenario

- Reflector A is tracking LEO spacecraft
- Reflector B starts slewing and disturbs spacecraft and reflector A
- Solution
  i) Slewing drive signal to B is processed by compensation logic to determine resulting spacecraft motion
  ii) Compensating signal equal and opposite to spacecraft motion is added to reflector A drive to compensate for slewing disturbance



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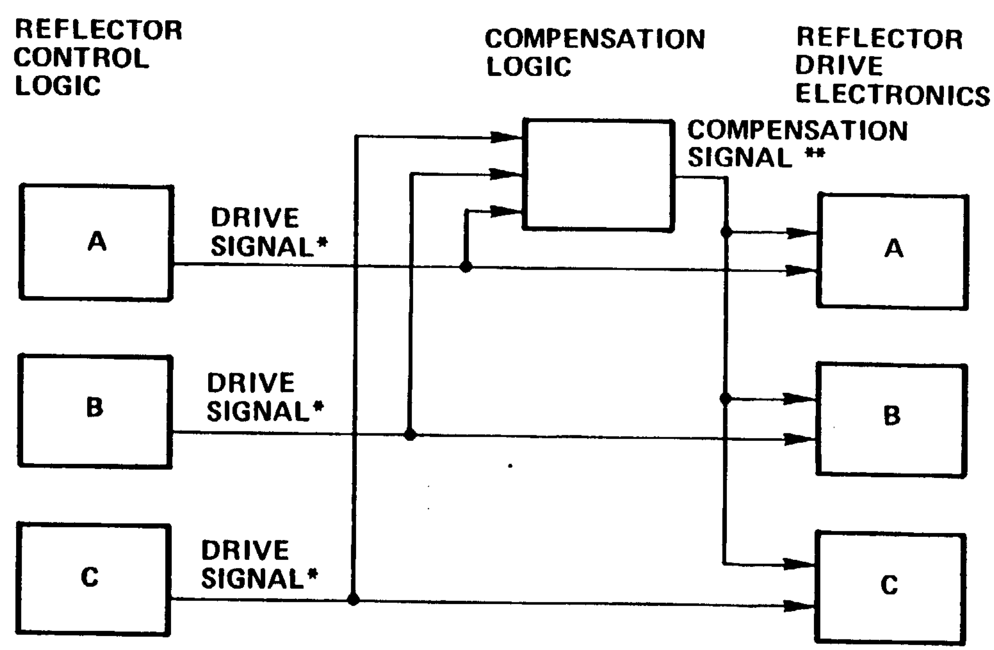
MULTIPLE REFLECTOR COMPENSATION SCHEMATIC



* SLEW OR TRACK
** THIS SIGNAL IS EQUAL AND OPPOSITE TO THE COMPOSITE S/C MOTION CORRESPONDING TO REFLECTOR DRIVE SIGNALS FROM A, B, C

CONTAMINATION

- Materials same as past Ford Aerospace spacecraft
- Propellants same as past Ford Aerospace spacecraft
- Relative location of optical surfaces same as past Ford Aerospace spacecraft
- Shielding can protect from direct impingent
- Ford Aerospace history indicates degradation not contamination of optical surfaces

CONCLUSIONS

- Structure feasible
- Thermal feasible
- Gimbals feasible
- Pointing budget reasonable and can be improved
- Contamination not a problem

TECHNOLOGY GOALS

Transmitters

Crystal Oscillators

Low Noise Front Ends

Digital Equipment

Filters

Low Complexity FEC Decoders

TRANSMITTERS

- o Resolution of the stable amplifier vs ILO approach to SSPA.
- o Development of larger IMPATT devices to reduce parts count.
- o Development of Combiner techniques which allow graceful degradation or development of module cross strapping techniques.
- o Improvement of TWTA reliability.
- o Improved parts characterization.

LOW NOISE FRONT ENDS

Development of reliable 60 GHz low noise devices.

- o HEMT
- o New Materials (InP)

DIGITAL EQUIPMENT

- 8 Bit A/D Converter with 150 to 200 mega-conversions per second.
- Multiplier capable of 300 to 500 mega-multiplies per second.
- Reliability consistent with mission life.
- 1ns RAM and ROM.

FILTERS

- o Development of low-loss EHF band-pass filters for multiplexer applications.
- o Development of narrow-band band-reject filters for power combiner.
- o Development of designs to maximize mechanical tolerances.
- o Utilization of over-sized cavities and higher order modes will fulfill these requirements.
- o Temperature stability at 60 GHz becomes a design driver.

60 GHz REQUIRE NO NEW TECHNOLOGIES

- O ALL ENABLING TECHNOLGIES ARE IN WORK OR PLANNED
- O THE CROSSLINK SYSTEM CAN BE BUILT AT ANY TIME--DATA RATE IS THE ONLY ISSUE
- O RELIABILITY DOMINATES PERFORMANCE LEVELS